National Park Service
U.S. Department of the Interior

Pacific Island Network
Vital Signs Monitoring Plan

Appendix E: Topical Working Group Report – Freshwater Biology

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Pacific Island Network (PACN)

Territory of Guam
War in the Pacific National Historical Park (WAPA)

Commonwealth of the Northern Mariana Islands
American Memorial Park, Saipan (AMME)

Territory of American Samoa
National Park of American Samoa (NPSA)

State of Hawaii
USS Arizona Memorial, Oahu (USAR)
Kalaupapa National Historical Park, Molokai (KALA)
Haleakala National Park, Maui (HALE)
Ala Kahakai National Historic Trail, Hawaii (ALKA)
Puukohola Heiau National Historic Site, Hawaii (PUHE)
Kaloko-Honokohau National Historical Park, Hawaii (KAHO)
Puuhonua o Honaunau National Historical Park, Hawaii (PUHO)
Hawaii Volcanoes National Park, Hawaii (HAVO)

http://science.nature.nps.gov/im/units/pacn/monitoring/plan/

Suggested citation:

Stephens, S. H. 2006. Appendix E: Freshwater biology report. *In*: HaySmith, L., F. L. Klasner, S. H. Stephens, and G. H. Dicus. Pacific Island Network vital signs monitoring plan. Natural Resource Report NPS/PACN/NRR—2006/003 National Park Service, Fort Collins, Colorado.

Last revision: 16 June 2005

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Acknowledgements:

This appendix was prepared with assistance from the Hawaii-Pacific Islands Cooperative Ecosystems Studies Unit (HPI-CESU), Task Agreement Number: J8080040032.

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FRESHWATER BIOLOGY EXECUTIVE SUMMARY

Freshwater ecosystems are often limited in spatial distribution, but are critical considerations for natural resource issues in all parks. These resources will be monitored as part of the National Park Service's Inventory and Monitoring Program. Despite small land areas, several different freshwater habitat types are present in the Pacific Island Network (PACN), some of which are unique within the United States. The Freshwater Biology topical workgroup has been constructed to gather information about all inland water bodies, fresh or brackish, including anchialine pools[1], manmade fishponds, streams, wetlands, bogs and similar areas. Habitats such as anchialine pool systems are rare worldwide, and only are present in Hawaii in the United States. Organisms which use these ecosystems include algae, other microorganisms, vascular and nonvascular plants, vertebrates, and invertebrates.

Routes of dispersal for the original plant and animal colonists of isolated Pacific islands required long ocean crossings, making it difficult or impossible for many groups to reach them. As a result, there are a small number of native freshwater species on Pacific islands, and they are frequently endemic. Native freshwater animals on Pacific Islands often have a marine background evident in their life cycles, illustrating that it is nearly impossible for truly freshwater animals to cross open ocean on their own.

Freshwater, brackish, and anchialine biological ecosystems are a finite resource on Pacific islands. With human occupation of the islands, many of these ecosystems have been highly modified or obliterated by land use practices, including agricultural, residential and commercial development. In other instances, new habitats have been created and are maintained by humans, such as the digging or enclosing of fishponds in Hawaii. Remaining aquatic ecosystems are extremely valuable for many rare and endangered species, for their natural ecosystem services, and in support of traditional agricultural and gathering practices. Several stressors to freshwater communities have been identified and may be placed in four categories:

- *Water diversion*, including groundwater withdrawal, surface diversion, and alteration of flow regimes. Diversion of surface water for agriculture and industry and withdrawal of groundwater for human consumption is one of the most significant stressors to freshwater biota on Pacific Islands. Water diversion reduces base flow in streams, thereby decreasing habitat availability, flow velocity, and channel size. Other effects of stream diversion include dampening of both the frequency and magnitude of periodic flooding events.
- *Land-use change*, including increased nutrient inputs, sedimentation and chemical pollutants, dumping, trampling, removal of riparian vegetation, hunting/fishing/gathering, and increasing urbanization. These changes make freshwater resources less suitable as habitat for native species. Additionally, physical alterations of native environments may facilitate the spread of alien species, which may be better able to compete under changed environmental conditions than natives.
- *Alien species*, including both terrestrial and aquatic plants and animals. These species can impact natives in several ways. Alien plants can outcompete native species by monopolizing resources such as space, light, or nutrients, or by excreting toxic compounds which prevent growth. Alien plants can also change the structure of freshwater communities by trapping sediment, slowing water flow, or contributing large amounts of

[1] Anchialine pools are brackish, tidally influenced, landlocked bodies of water with underground connections to the ocean. They are surface expressions of extensive subterranean ecosystems dependant on the mixing of fresh and saline groundwater (Polhemus et al. 1992).

litter to pools. Alien animal species may prey upon native plants and animals, compete for space, or carry parasites which harm natives. The impacts of alien species may be felt many miles from the effects of other human activities.

- *Climate*, including storms and drought conditions, as well as the effects of global climate change. Storms and droughts both may cause significant changes to aquatic ecosystems. An increase in storm intensity, and possibly frequency, is predicted for Pacific Islands with global climate change (IPCC 2001). Other predicted consequences of global climate change are a shift in the elevation of the trade wind inversion layer, which will change the elevation of cloud formation and rainfall, and sea level rise, which will inundate coastal ecosystems.

Inventorying of freshwater physical and biological resources has occurred to varying degrees in the PACN parks, though little or no long-term monitoring of freshwater biology has taken place. This report identifies information needs for these habitats, which include basic data on habitat extent, water quality, and community composition, to help resource managers understand the degree of habitat loss and the priorities for conservation of remaining habitats. In addition, this report identifies several areas where research is needed to more fully understand the ecology of these systems and organisms. Freshwater ecosystems differ greatly among PACN parks.

Freshwater resources of American Memorial Park (AMME), on Saipan, include a coastal mangrove swamp and wetland, one of the last remaining coastal wetlands in the Mariana Islands. Its hydrology is incompletely understood. Several threatened or endangered species are found in the wetland. War in the Pacific NHP (WAPA), on Guam, has several streams and coastal and perched higher-elevation wetlands. The National Park of American Samoa (NPSA), on the islands of Tutuila, Ofu, Olosega, and Tau, has several streams, and coastal marshes. A mangrove wetland is located in close proximity to the park boundary in Vatia. Many native aquatic species are found in these ecosystems.

The USS Arizona Memorial (USAR), on Oahu, Hawaii, contains no freshwater resources, but several highly urbanized streams drain into Pearl Harbor, where the park is located. Kalaupapa NHP (KALA), on Molokai, Hawaii, contains several streams, springs, and seeps, an inland brackish fishpond, and a crater lake which is unique within the United States. Haleakala NP (HALE), on Maui, Hawaii, contains several high-quality streams and high-elevation montane bogs and ponds which support several threatened and endangered species.

Five parks are located on Hawaii Island, Hawaii. The Ala Kahakai NHT (ALKA) stretches across the majority of the coast of the island, and crosses numerous anchialine pools, streams, fishponds, and coastal wetlands. Several threatened and endangered species are found along the trail route. Pu`ukohola Heiau NHS (PUHE) contains a stream and estuarine wetland within its boundaries. Kaloko-Honokohau NHP (KAHO) contains numerous anchialine pools, two fishponds, and a coastal wetland. Several threatened or endangered species are found within the park. Pu`uhonua o Honaunau NHP (PUHO) contains several anchialine pools and manmade fishponds. Hawaii Volcanoes NP (HAVO) contains anchialine pools, intermittent streams, and mid-elevation bogs and seeps.

The diverse freshwater and brackish ecosystems within the PACN contain a wide array of biological resources, for which several areas of concern for management have been identified. The NPS is one of the few agencies within the Pacific Island region with jurisdiction over these resources and a mandate to protect them in an unimpaired state. Well-informed management is crucial for maintenance of their ecological integrity, so that these species and ecosystems are not destroyed.

INTRODUCTION

DEFINITION OF TOPIC AREA

This workgroup includes all inland water bodies, fresh or brackish, including anchialine pools and brackish fish ponds such as Kaloko Pond at KAHO. Anchialine pools are tidally influenced brackish land-locked bodies of water with extensive subterranean connections to the ocean. Streams, wetlands, bogs, seeps, and similar habitats are included in this topic area. Emphasis is on flora (algae and higher plants) and fauna (vertebrates and invertebrates) in these ecosystems, especially obligate species. Important issues addressed include health of native populations (especially threatened and endangered species), presence and impacts of alien species and quality of habitat in support of native species.

BACKGROUND

Inland and Freshwater Pacific Island Ecosystems

Distribution of fresh water on oceanic islands typically results in isolated surface resources. Limited surface connections often further the impression of resource isolation, although extensive shallow groundwater connections between surface features are often present. On Hawaii and Maui in particular, which have young morphology with lava tubes and atypical topography, there is not a clear understanding of subsurface hydrology. This presents challenges to understanding groundwater dynamics.

Pacific Islands share many of the same stressors and drivers affecting freshwater biology. Stressors and other agents of change (e.g., land use influences, water withdrawals, and exotic species proliferations) frequently affect multiple water bodies and require an integrated approach to monitoring across drainages and even islands. Human population growth and immigration affects these islands in similar ways, as increasing demand for water for consumption and irrigation and scarce land area put more pressure on aquatic habitats. Globally, freshwater ecosystems are considered to be among the world's most vulnerable (UNEP 2004)

Multiple types of inland and freshwater ecosystems are found on tropical Pacific islands. Polhemus and colleagues (1992) classify inland waters into 18 types, and recognize two types of estuaries (true estuaries and spring-fed estuarine pools). These include subterranean systems, flowing surface waters, and standing surface waters. Each of these categories is further divided. Subterranean systems are either haline (including anchialine) or fresh. Flowing surface waters are divided into continuous and interrupted perennial streams, intermittent streams, seeps and springs (rheocrenes), and manmade ditches and flumes. Standing surface waters are divided into palustrine (mid- or high-elevation bogs, swamps, and marshes, lowland playas, and perennial lowland swamps, marshes, and anchialine pools) and lacustrine (reservoirs and fresh or saline lakes and ponds). Nationally, wetlands are classified into four categories (Cowardin et al. 1979): estuarine, riverine, lacustrine, and palustrine). Many of these systems are found within PACN parks.

Water and aquatic resources are often limited in spatial distribution, but are critical considerations for natural resource issues in all parks. Stressors such as alien species introductions and human land use issues affect all parks nationwide to some degree, although these may be of greater magnitude on small land masses. Additionally, on Pacific Islands, native amphidromous species, which migrate between freshwater and the ocean (Radtke & Kinzie 1991), require a broader conception of fresh-water habitat than that used in other regions.

The Hawaiian Islands are located within the central Pacific, and parks in these islands are located on relatively young high volcanic islands from sea level to over 13,000 feet. Freshwater resources are varied, including high-elevation bogs and lakes, streams and seeps, sloped wetlands, anchialine pools, fishponds and low- to mid-elevation wetlands. Land use and park visitation also are variable. Due to their isolation, more endemic species are located here than in the other two regions.

Guam and Saipan are located within the western Pacific, and are volcanic/limestone and limestone islands, respectively; parks on these islands are located from sea level to several hundred feet. These islands were significantly affected by military occupation during World War II and have severe environmental effects from this era. Freshwater resources include coastal mangrove wetlands, sloped and other types of wetlands, and streams.

American Samoa is located on high volcanic islands within the south Pacific. The National Park of Samoa extends from sea level to 1,610 ft in units on three islands, and agricultural activity is extensive within its boundaries. Freshwater resources within the park include streams, a mangrove wetland, and lowland marshes.

Previous monitoring and current needs

Little long-term monitoring of freshwater biology has taken place in PACN parks, and most information that exists results from surveys, inventories, or short-term studies. For example, selected animal groups have been inventoried in anchialine pools and fishponds in KAHO, and some short-term studies have been conducted (e.g., waterbird reproduction). In other parks, only inventories have been conducted or are in planning stages (e.g., anchialine pools in HAVO, streams in NPSA), and some resources have not been inventoried (e.g., wetlands and bogs in WAPA).

Current needs in these habitats are for basic data on habitat extent, water quality, and community composition so that monitoring plans can be established appropriately. Baseline information to be collected includes hydrology, water quality data, presence of native (especially threatened and endangered plant, vertebrate, and invertebrate) species and presence of alien species (especially known invasive and/or pest species). Freshwater resources located within parks vary; e.g. several parks have streams or coastal wetlands, while only one park has high-altitude lakes.

MONITORING OBJECTIVES

Freshwater and anchialine biological habitats are a finite resource in the Pacific Island Network (PACN). These areas have often been modified or obliterated through land use practices, including agricultural, residential and commercial development. Inland aquatic habitats are extremely valuable for their natural ecosystem services as well as their support of traditional agricultural and gathering practices. Documentation of historic and contemporary spatial extents of these habitats and basic biotic inventories are needed to help resource managers understand the degree of habitat loss and establish priorities for conservation of remaining habitats. General objectives for monitoring freshwater habitats include:

- Documenting changes in extent and diversity of habitats;
- Documenting changes in the distribution, abundance or diversity of invasive species;
- Documenting the nature of the distribution, abundance, or diversity of native species, including both natural fluctuations as well as those caused by external influences such as habitat alteration and introduced species;
- Monitoring the influence of hydrologic cycles on aquatic biology and increasing the understanding of groundwater and surface water interactions as they relate to aquatic systems within the Parks;
- Improving our understanding of watershed processes, including hydrogeomorphic interactions and influences of intermittent users of these habitats (humans, migratory waterfowl, etc.).

Primary goals of monitoring, as defined by the National Park Service Inventory and Monitoring Program (with the addition of a sixth goal for the PACN regarding resources with shared natural and cultural value), are to:

- Determine status and trends in selected indicators of park ecosystem(s) condition to allow managers to make better-informed decisions and to work effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.
- *Provide data to better understand, protect, and manage important resources that share cultural and natural value.*

The identification and monitoring of Vital Signs, or ecosystem elements selected to provide the most information on ecosystem health, is an integral part of this program.

MANDATES, POLICY, AND LEGISLATION

The National Park Service operates under a hierarchy of legislative mandates, including federal laws, executive orders, Department of the Interior and National Park Service directives, and state or territorial regulations[2]. Cooperation with numerous overlapping federal and local agencies is necessary to achieve the NPS' objectives.

INVENTORY & MONITORING PROGRAM

The Natural Resource Challenge (NRC), initiated in 1999, is an action plan for preserving natural resources through the National Park Service (NPS). The NRC assisted NPS to establish 32 Inventory and Monitoring networks, which include 270 National Parks. In the Networks, parks are grouped that share geographical and natural resource characteristics. The I&M Program is designed to first complete basic inventories of natural resources in parks on which to base long-term monitoring efforts. Monitoring programs are based on monitoring critical

[2] See also: http://science.nature.nps.gov/im/monitor/LawsPolicy.htm.

parameters (Vital Signs) to be incorporated into natural resource management and decision-making.

The NRC places a special emphasis on water and air quality-related monitoring, in order to emphasize the integration of those elements with the current water and air quality programs. Water quality monitoring is separately funded, though it will be fully integrated with the core park vital signs monitoring funding. Within the PACN, as with other geographic regions, it will be necessary for close integration with other water quality related monitoring, such as that conducted by state, territorial and federal agencies. Such inter-agency and cooperative monitoring is especially crucial for water-related topics, as land use activities outside of park boundaries yet within the same watershed impact water quality within the park.

FEDERAL LEGISLATION AND INTERNATIONAL AGREEMENTS

Freshwater aquatic habitats have received considerable legislative attention, in part due to pervasive habitat loss and degradation throughout the nation. Wetlands and estuaries, as well as their associated biota, have received emphasis. Anchialine habitats (sometimes referred to as mixohaline wetlands) are a rare type of ecosystem worldwide (Hawaii is the only state that possesses them). These habitats are classified as "special aquatic sites", similar to wetlands. The primary federal legislation and international treaties that address freshwater habitats or organisms within national parks are identified below.

- Rivers and Harbors Act (1899)- Regulates activities that may affect navigation and navigable waters, including coastal waters, wetlands and streams. Permits are needed for any activity that crosses these aquatic ecosystems (e.g., utility lines, roads).[3]
- National Park Service Organic Act (1916)- This Act formed the National Park System to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations"[4].
- Migratory Bird Treaty Act (1918)- Established that all migratory birds are protected from commercial trade. The Migratory Bird Treaty is an international agreement with several countries. Several species present in PACN wetlands are protected by this Act[5].
- Estuary Protection Act (1968)- Authorized the Secretary of the Interior to study and inventory estuaries of the United States. Federal agencies were also required to assess the impacts of commercial and industrial developments on estuaries[6].
- National Environmental Policy Act (1969)- Mandates that all federal projects and actions consider environmental effects of proposed activities, and provides for public input[7].
- General Authorities Act (1970)- Reinforced the Organic Act, and stated that all park lands are united by a common preservation purpose regardless of title or designation[8].
- Costal Zone Management Act (1972)- Established a voluntary program to assist states and territories in developing and implementing coastal zone management programs, including

[3] http://laws.fws.gov/lawsdigest/riv1899.html
[4] http://www.nps.gov/legacy/organic-act.htm
[5] http://laws.fws.gov/lawsdigest/migtrea.html, see also http://laws.fws.gov/lawsdigest/treaty.html
[6] http://www4.law.cornell.edu/uscode/16/ch26.html
[7] http://ceq.eh.doe.gov/nepa/regs/nepa/nepaeqia.htm
[8] http://www.nps.gov/legacy/legacy.html

designating coastal areas, identifying uses to be regulated and use priorities and establishing mechanisms for regulating uses[9].

- Federal Water Pollution Control Act (Clean Water Act) (1972)- Authorized the EPA to develop programs to restore and maintain the physical, biological and chemical integrity of the nation's waters. The Act also established a permit program which is run by the U.S. Army Corps of Engineers and EPA, who regulate activities affecting all "waters of the United States", including streams, lakes, and "special aquatic sites", such as wetlands and anchialine ponds. This program applies to all park properties in the Pacific. Also, regard was to be given to improvements necessary to conserve waters for public water supplies, propagation of fish and aquatic life, recreational purposes and agricultural and industrial uses.[10] Water quality criteria have been established for aquatic life separately from human water quality criteria[11].
- Endangered Species Act (1973)- Provides for protection of fish, wildlife and plant species that are listed as threatened or endangered in the U.S. or elsewhere. Guidance is provided for listing species, as well as for establishing recovery plans and designating critical habitat for listed species. Procedures for federal agencies to follow when taking actions that may jeopardize listed species are outlined. The Act also includes provision for exceptions and exemptions[12].
- Convention Against International Trade in Endangered Species (1975)- This international agreement ensures that international trade does not threaten the existence or survival of endangered or threatened species. CITES regulates the trade of species listed as endangered or threatened by the country of origin, the importing country, or any countries that the species might travel or pass through.[13]
- Magnuson-Stevens Fishery Conservation and Management Act (1976)- This act recognizes that marine and anadromous fish are valuable and renewable natural resources and that they have been damaged by loss of essential habitat and overfishing. This law finds it necessary to implement a national program for the conservation and management of fisheries to prevent overfishing, rebuild stocks, and ensure conservation before irreversible harm occurs. This act specifically applies to anadromous fish species regardless of their location and also offers protection for offshore species when their juveniles use nearshore habitats such as reefs[14].
- Resource Conservation and Recovery Act (1976)- Regulated identification, transportation and management of solid and hazardous waste[15].
- Redwood National Park Act (1978)- Expanded the General Authorities Act to state that all parks were to be managed and protected "in light of the high public value and integrity of the national park system", and that no activities were to take place in the parks detrimental to the values for which they were established, unless mandated by law or act of Congress[16].

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9 http://coastalmanagement.noaa.gov/czm/czm_act.html
10 http://www4.law.cornell.edu/uscode/33/ch26.html
11 http://www.epa.gov/watersciencecriteria/aqlife.html
12 http://endangered.fws.gov/ESA/ESA.html
13 http://laws.fws.gov/lawsdigest/treaty.html
14 http://laws.fws.gov/lawsdigest/fishcon.html
15 http://www4.law.cornell.edu/uscode/42/ch82.html
16 http://www.nps.gov/legacy/legacy.html

- Emergency Wetlands Resources Act (1986)- Required the establishment of a National Wetlands Priority Conservation Plan and required states to include wetlands in their Comprehensive Outdoor Recreation Plans. It also required the Secretary of the Interior to report to Congress on wetlands loss, including an analysis of the role of Federal programs and policies in inducing such losses and to complete the National Wetlands Inventory[17].
- National Invasive Species Act (1996)- Mandates federal agencies to manage aquatic invasive species, including developing and carrying out control programs and developing programs to understand ecological impacts of alien species[18].
- National Parks Omnibus Management Act (1998)- Clarified the role of NPS as a conservation and science agency. Among the items it specifically mandated were the establishment of an inventory and monitoring program to obtain baseline information on natural resources, the development of a broad, rigorous scientific research program which could be expanded by establishing cooperative agreements with outside groups and the hiring and training of scientists within the NPS. Additionally, NPOMA granted protection for key natural resources within the parks by restricting sensitive information from release under the Freedom of Information Act[19].
- Estuaries and Clean Waters Act (2000)- Encouraged the restoration of estuary habitat through more efficient project financing and enhanced coordination of Federal and non-Federal restoration programs. Established an interagency council charged with developing a national estuary habitat restoration strategy and providing grants to entities to restore and protect estuary habitat[20].
- National Aquatic Invasive Species Act (pending)- Aims to prevent the introduction of aquatic invasive species by ships, interbasin transfers, and other pathways. Also makes funding available for aquatic invasive species management plans, rapid response teams, research, education, and monitoring[21].

EXECUTIVE ORDERS

- Executive Order 11990: Protection of Wetlands (1977); amended by EO 12608 (1987)- Intended to minimize the destruction, loss, and degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands. Directs federal agencies not to undertake or provide assistance for new construction in wetlands unless no practicable alternative is found and all practicable steps are taken to minimize harm to wetlands.
- Executive Order 12962: Recreational Fisheries (1995)- Mandates that Federal agencies improve the quantity, function, sustainable productivity, and distribution of U.S. aquatic resources for increased recreational fishing opportunities. Federal agencies are instructed to aggressively work to identify and minimize conflicts between recreational fisheries and their respective responsibilities under the ESA.
- Executive Order 13112: Invasive Species (1999)- Federal agencies whose actions may affect the status of invasive species shall: (1) identify such actions, (2) use relevant programs and authorities to prevent, control, monitor, and research such species, and (3)

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[17] http://www4.law.cornell.edu/uscode/16/ch59.html
[18] http://www4.law.cornell.edu/uscode/16/ch67.html
[19] http://www4.law.cornell.edu/uscode/16/ch79.html
[20] http://www4.law.cornell.edu/uscode/33/ch42.html
[21] http://www.nemw.org/NAISA%20one%20pager.pdf

not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere.

- Executive Order 13186: Migratory Birds (2001)- Federal agencies are required to protect migratory birds on the Migratory Bird Treaty list (50 C.F.R. 10.13). This list includes the Hawaiian coot (*Fulica alai*), Hawaiian duck (*Anas wyvilliana)*, Hawaiian moorhen (*Gallinula chloropus sandvicensis*), Marianas moorhen (*Gallinula chloropus guami*), Black-crowned night heron (*Nycticorax nycticorax*), and Hawaiian stilt (*Himantopus mexicanus knudseni)*, as well as several species of migratory shorebirds which are frequently present in coastal wetlands.

NPS MANAGEMENT POLICIES

National Park Service Management Policies were revised in 2000 and contain extensive guidance on Natural Resource Management[22]. All monitoring activities must fall within the framework of these Management Policies.

Park enabling legislation

Legislation enabling the National Parks describes the purpose and mission of each park. (An exception in the PACN is USAR, which operates under a Memorandum of Understanding with the US Navy.) The *ahupua`a* resource management system, identified in park enabling legislation through the mandate of preserving traditional land use systems and practices, is probably the most explicit reference to freshwater habitats in the Hawaiian Islands. Legislation establishing individual parks may also identify specific freshwater resources for research, monitoring and protection. Mandates for park resource preservation may also require maintaining these resources in a way that is incompatible with restoration of a natural landscape, such as maintaining vegetation as it occurred during a certain historical period. These mandates may supercede other restoration objectives for the park.

Park-specific management policies and priorities

Some parks will have park-specific management policies required to meet the mission or conditions of their enabling legislation. These park-specific policies must be considered in the development of the park's monitoring plan and in the Vital Signs selection process. Park-specific management policies may include Superintendent's compendia.

Director's Orders and Other NPS Documents

Several DOI and NPS directives and documents provide guidance and support for natural resource management.

- Memorandum to Secretary of the Interior from the Solicitor (16 April 1998): This memorandum analyzes the Secretary's legal duty to protect parks from activities on non-NPS land adjacent to park boundaries. While not explicit in the Redwoods Amendment, this memo provides support for involvement in natural resource issues lying outside the park boundary.
- D.O. 55 (2000): D.O. 55 further clarifies language within the NPS Organic Act and the 1970 Act for Administration including the Redwood Amendment by reiterating the single

[22] See http://www.nps.gov/refdesk/mp/chapter4.htm

mission of the NPS: to preserve resources. This Director's Order also clarifies what constitutes impairment, park resources and values, and provides guidance for decision making, including requiring scientific data in accordance with the National Parks Omnibus and Management Act

Park planning documents

Various park management plans recognize freshwater or brackish habitats or species as important natural resources.

- AMME- The 1982 Resource Management Plan overview includes the wetlands and several associated bird species as the primary terrestrial natural resources within the park, and states that they will be managed.
- WAPA- The 1983 General Management Plan/EIS states that several streams and a small wetland area are present within the park; the streams are degraded, but the wetland is a priority for conservation. The 1997 Resource Management Plan lists preservation of “natural features such as native plant communities and stream and marine bed environments” as a major natural resource issue.
- NPSA- The General Management Plan/EIS (1997) lists Laufuti Stream and others (including intermittent streams) as important natural resources, with the potential for endemic fish species to live within them.
- USAR- No freshwater biological resources are located within this park.
- KALA- The 1994 Resource Management Plan lists the need to determine status of Waikolu Stream biology, manage Kauhako Crater and Lake, and determine water rights, uses, and requirements for Waikolu Stream as management concerns.
- HALE- The 1995 General Management Plan/EIS discusses plans for visitor and water use in the streams in the Kipahulu area, and lists native fish and the native prawn among its biological resources. It also discusses the eligibility of Palikea and Pipiwai Streams (in `Ohe`o Gulch) and Koukouai Stream for National Wild and Scenic River status.
- ALKA- Management plans have not been finalized (as of September 2004) for this newly-established park.
- PUHE- An undated (post-2000) Resource Management Plan refers to Makeahua Wetland and states the need to determine its use by native birds.
- KAHO- The 1991 Resource Management Plan lists protection of anchialine pool resources (at the time being affected by eutrophication) and restoration of waterbird habitat as two of its major natural resource issues. In addition, a candidate endangered shrimp species may live within the anchialine pools, and the RMP lists the need to inventory this species.
- PUHO- The 2001 Development Concept Plan/ Environmental Assessment refers to the anchialine pools and associated wetland as important resources.
- HAVO- The 1993 update to the Resource Management Plan states that a water resources management plan needs to be developed for the park, but otherwise does not specifically discuss aquatic resources. The 2000-2005 Strategic Plan does not specifically discuss aquatic resources within the park.

Traditional uses

Traditional uses of biological resources by native Hawaiians are protected in Hawaii under the State Constitution. Such rights include gathering plants, algae, and animals from forests, streams, and the ocean. Cultivation of kalo (taro, *Colocasia esculenta*), an aquatic plant, is also protected. Access to these resources is maintained within parks unless specifically limited. Kalo farming is practiced in HALE by the Kipahulu `Ohana, a native Hawaiian nonprofit group, in the Kipahulu section of the park. Both subsistence farming (agriculture and livestock) and fishing are permitted within NPSA.

LEGISLATION AND POLICY

Primary agencies responsible for aspects of freshwater or brackish water resources at the state or territorial level are listed below. The degree to which these agencies are funded and/or staffed to enforce their mandates varies. Several government-sponsored partnership groups, also included in this section, are potential partners for NPS Vital Signs monitoring.

Hawaii (USAR, KALA, HALE, ALKA, PUHE, KAHO, PUHO, HAVO)

- *Hawaii State Constitution*- The State of Hawaii constitution protects native gathering rights, including those of plants and animals in forests, streams, and along coasts, as well as the cultivation of kalo (*C. esculenta)*, an aquatic plant.
- *Department of Land & Natural Resources (DLNR)*- Administers the Hawaii Biodiversity Joint Venture, a partnership with USFWS which provides funding to projects for habitat restoration. The DLNR is responsible for the conservation of aquatic life, wildlife and land plants in the State of Hawaii.

    Division of Aquatic Resources- Part of the DLNR, this agency is responsible for the protection and conservation of fresh water and marine resources in the State of Hawaii.

    Commission for Water Resource Management- Part of the DLNR, the CWRM administers the Stream Channel Alteration Process and formulates instream flow standards to preserve streams for the public interest.
- *State Department of Health (DOH)*- Issues EPA Section 401 Water Quality permits, establishes and enforces state water quality standards. The DOH has also established a stream biomonitoring protocol in conjunction with the NRCS which it uses in conjunction with its Total Maximum Daily Load (TMDL) program.
- *Hawaii Coastal Zone Management* Program- Issues permits for coastal development in Shoreline Management Areas as well as county shoreline setback areas. The purpose of the program is to preserve coastal resources, including wetlands, estuaries, and anchialine pools.
- *Natural Resource Conservation Service (NRCS)*- This federal agency provides guidance to Hawaii Soil and Water Conservation Districts. The NRCS has also developed a stream biomonitoring protocol for use in Hawaiian streams.
- *Counties*- Issue various permits for grading and other uses of coastal and upland areas.
- *Partnerships*- HALE participates in the East Maui Watershed Partnership and the Leeward Haleakala Watershed Restoration Partnership. KALA participates in the East Molokai Watershed Partnership. HAVO participates in the `Ola`a-Kilauea Partnership.

Samoa (NPSA)

- *Department of Marine & Wildlife Resources*- Protects and manages the Territory's marine and wildlife resources "to the extent intended to best benefit the people of American Samoa while ensuring the integrity of such resources for posterity".
- *American Samoa Environmental Protection Agency*- Develops and implements programs to protect the environment and public health from harmful impacts on air quality and water quality and promotes proper waste disposal practices.
- *Partnership*- Le Tausagi is an interdepartmental group formed "to coordinate and implement existing and proposed environmental education (EE) efforts in order to provide a more coherent and powerful EE program to the public".

Guam (WAPA)

- *Guam Environmental Protection Agency*- Monitors water quality, issues permits, and enforces regulations. Has recently (2002) begun planning a biological water monitoring program, the Freshwater Periphyton and Benthic Macroinvertebrates Assessment Program. An interagency water planning committee has been formed to promote collaborative partnerships to identify water resource problems and priorities, and collectively develop and implement effective resource protection and restoration activities.
- *Department of Planning*- Implements a Coastal Zone Management Plan.

CNMI (AMME)

- *Department of Lands & Natural Resources*- Includes the following three agencies:
  - *Coastal Resources Management Program*- Coordinates permitting, planning, and implementation of coastal zone management and watershed activities, and administers federal funds related to coastal zone management.
  - *Division of Fish and Wildlife*- Agency responsible for conservation of fish, game, and wildlife, and protection of endangered and threatened species. Conducts research, monitoring, regulation, enforcement, planning, and management activities.
  - *Division of Environmental Quality*- Conducts water quality studies and monitoring, issues permits.

GEOGRAPHIC SETTING AND ECOLOGICAL MODELS

All the PACN network parks are located on tropical islands in the Pacific Ocean. Eight of the parks are in the Hawaiian Islands in the Central Pacific between 19 and 22 degrees North latitude. Two PACN parks are situated in the western Pacific Ocean between 13 and 15 degrees north latitude in Micronesia. NPSA is on the Polynesian islands of American Samoa, approximately 14 degrees south latitude.

The extreme isolation of Pacific Islands has resulted in a limited diversity of native species, but a high degree of endemism. As in many terrestrial plant and animal groups, freshwater native species richness generally declines and the degree of endemism increases with distance from a continent (Font 2003). Because of the vast ocean distances separating freshwater habitats on different islands, freshwater Pacific island fauna have in many cases evolved from marine ancestors; marine stages in their life cycles allow these organisms to cross the ocean. Freshwater and brackish systems in the PACN are vulnerable to invasions of alien species, especially when natural environmental conditions have been modified by human activity.

There is great variation among freshwater and brackish habitats in PACN parks. Habitat types include perennial and intermittent streams, montane bogs and ponds, a lowland lake, coastal wetlands and anchialine pools with varying degrees of salinity, and seeps and springs in both mid- to high-elevation and coastal areas.

CLIMATE

The largest two Hawaiian parks, HAVO and HALE, include within their boundaries several climatic zones with a range of rainfall regimes. In general, the eastern windward portion of HAVO has high rainfall, which diminishes upslope, particularly above the trade wind inversion layer near 1,830 m (6,000 ft) elevation. The upper elevations of the park are moist to very dry, and the summit of Mauna Loa receives on average <500 mm precipitation. The leeward, western portions of HAVO are in rain shadows of Mauna Loa and Kilauea summit, and are typically dry (Giambelluca et al. 1986). HALE also has a range of climates, as it extends from sea level on the windward, eastern slope of Haleakala to the summit of East Maui. Annual precipitation in the park varies from 1,250 mm in the Crater, the southern slope, and Kaupo Gap to >6,000 mm on the upper northeastern slopes of Haleakala (Giambelluca et al. 1986).

The three West Hawaii Island parks (PUHE, KAHO, and PUHO) are in relatively low rainfall areas with constant warm temperatures and pronounced daily wind patterns of land and sea breezes (Blumenstock and Price 1967). Because ALKA covers a large linear coastal route from north to southeast Hawaii, the rainfall pattern is variable. KALA, on the north shore of Molokai, receives 1,000 mm of precipitation annually at sea level and >3,000 mm at the upper elevations of Waikolu Valley (Giambelluca et al. 1986). USAR, on Oahu, is located within Pearl Harbor on the dry leeward side of the island in an area than has on average 600 mm rainfall per year.

The climate of Guam and the Northern Marianas (CNMI), including Saipan, is warm, wet, and tropical. The rainfall pattern is strongly seasonal with a wet season from July to November and a pronounced dry season from December to June. Average annual rainfall of the Marianas is 2,160 mm (85 in) (Baker 1951), and on Guam the annual mean is 2,175 mm (Mueller-Dombois and Fosberg 1998). Tropical cyclones are yearly events, and occur during the monsoonal wet season. NPSA, in American Samoa, has a warm tropical climate with little seasonal variation in temperature. Rainfall is high in the four units of the park, and seasonal with greater monthly means from October to May and a dry season from June to September (Whistler 1994).

Climate across the Pacific is strongly affected by the El Nino-Southern Oscillation cycle (ENSO), as well as the Pacific Decadal Oscillation (PDO). Changes in rainfall naturally impact freshwater resources. For example, stream flow in Hawaii in the winter months has been observed to be lower following dryer El Nino periods and higher following wetter La Nina periods (Oki 2004). For a more detailed discussion of ENSO and PDO, see the Climate and Air Quality report in the Supplemental Documents.

GEOMORPHOLOGY

Underlying geology plays a large role in the occurrence and form of freshwater habitats. Parks on Pacific Islands differ from most others in the National Park System both in that these islands are isolated land masses surrounded by salt water, and are in the youth of their geology. These characteristics have a profound effect on the abundance of freshwater resources and their characteristics. Fresh groundwater “lenses” permeate areas of the bedrock above seawater and saline groundwater. These lenses form as rainwater percolates through rock layers, and are frequently located near sea level in coastal areas.

Role of substrate

Underlying geology on northern Guam and Saipan differs from the other PACN islands, where karstic limestone, rather than volcanic rock, makes up the surface substrate. Freshwater lenses on Guam and Saipan are generally thinner than on Hawaii or Samoa, so withdrawal of groundwater for drinking can be a large problem. Age of substrate also plays a role in groundwater movement; for example, water seeps through remnant lava tubes and holes in young basalt rock in the Hawaiian Islands along different flow paths than those predicted from typical groundwater models. This can also create uncertainties in both the vulnerability of groundwater lenses to saltwater intrusion and in predictions of movement of anthropogenic contaminants.

Stream flow regimes

Pacific Island streams are typically fed by a combination of groundwater and precipitation. They typically have frequent and unpredictable periods of high flow associated with rainfall (e.g., Oki & Brasher 2003). These flooding events can be hazardous to human life. Native stream fauna are adapted to frequent flooding, for example, the life histories of amphidromous and catadromous species are linked to flooding events. These events also exclude many alien animal species from the upper reaches of streams that have natural flow regimes (Brown et al. 1999).

Wetland hydrology

Wetlands in the PACN form from several sources. Coastal wetlands can be either groundwater fed, surface water fed, or both. Anchialine pools are a specific type of coastal ecosystem that consists of both surface features and a subterranean network. They are unique to Hawaii within the United States (Maciolek 1987). Mid-elevation and high-elevation wetlands and seeps are fed by perched groundwater tables and rainfall.

SOCIAL CONCEPTS

The Hawaiian ahupua`a concept regulates land and water resource use in the traditional system of land division, which typically stretches from the mountains to the open ocean. The ahupua`a concept differs somewhat from the modern Western concept of watershed-based management in that it includes social and cultural interactions within and among different groups, and it extends out to the coral reefs and nearshore waters, which were important for the Hawaiian people. Nevertheless, it is frequently equated with watershed-based management. Many recently formed management partnerships in Hawaii operate with this in mind.

The traditional system of land use in American Samoa centers on the village. Lands were held in common for the village, and traditionally the village councils would grant tenure or land use privileges to families within the village’s district (O`Meara 1987). Unlike in the Hawaiian Islands, for the most part American Samoan land tenure still operates according to traditional practice. Traditional systems of land tenure in both Guam and the CNMI have been, for the most part, lost during successive phases of non-native governance (Johnson 1969, McGrath and Wilson 1987).

BIOLOGY AND BIODIVERSITY

Many biological groups on isolated islands (whether these are isolated oceanic islands or 'island' bogs on mountain tops separated hundreds or thousands of miles from similar habitats) undergo specialization and speciation. This process can lead to adaptive radiations, in which several new species are derived from a single ancestral form. One aquatic group in which this has occurred is the endemic damselfly genus *Megalagrion* in the Hawaiian Islands, which consists of 22 species and 3 subspecies, found in habitats ranging from lowland streams to high-elevation seeps (Polhemus & Asquith 1996). Because these organisms often evolve in the absence of strong predation, competition, or herbivory, they often lack the behavioral, biochemical, or structural defenses common to organisms evolving on continents. Active management of these organisms, which may be restricted to only a few areas or populations, is necessary in order to preserve biodiversity.

Level of study

Many Pacific Island freshwater species are poorly studied, and may be under-represented in federal, state and territory threatened and endangered listings. This gap in past research as compared to levels of research focusing on flowering plants, birds, and coral reef species is problematic, especially since freshwater supply issues for human use on Pacific Islands frequently lead to diversions and groundwater withdrawals. Some groups have not been inventoried in all of the parks, while some groups have been inventoried more comprehensively than others. The overall level of past study is more comprehensive in Hawaii than on the other island groups. Gaps in knowledge of the reproductive characteristics and population dynamics of some species are also a concern. Research on ecology and community dynamics of systems like anchialine pools is also needed. It is important to understand the population dynamics of native aquatic species, especially species of concern and threatened and endangered species.

- *Algae*- The freshwater algal flora of the Pacific Islands has been under-studied compared to those of other regions in the United States (e.g., Filken et al. 2003). In the U.S., community composition and biomass of algae are often used as water-quality indicators (most frequently as indicators of eutrophication), and their historical remains may also be used to discern patterns of climate change in lakes and wetlands (such as temperature or salinity changes) (Lowe & Pan 1996). Algae frequently form the most important food source in aquatic ecosystems. For example, Hawaiian stream fishes utilize algae as some or all of their diets (Kido 1997), and algae serves as the main food source for several fish and crab species in brackish mangrove ecosystems (Skelton & South 2002).
- *Plants*- Native freshwater plant habitat and distribution on Pacific Islands has been drastically altered by humans. Historically, low-lying wetland and coastal areas were the first to be altered by human activities, such as taro or rice farming, salt production, or grazing in wetland pastures; consequently, many plant species living in these areas have been significantly affected (Mueller-Dombois & Fosberg 1998). Aquatic flowering plants and ferns have been studied and described, while much less is known about algae, mosses, and non-vascular plants.
- *Invertebrates*- Several endemic insect species have aquatic stages in their life history. For example, some adults of the endemic Hawaiian damselfly genus (*Megalagrion* spp.) live in terrestrial riparian areas. Females deposit their eggs in or near water, and the larvae live in water until they emerge as adults (Polhemus & Asquith 1996). Several of these species are restricted to small, remote springs and seeps. Vegetation in wetlands or riparian areas

is important habitat for *Megalagrion* species. Several endemic invertebrate species such as snails and shrimp have also evolved in Hawaii, Samoa and the Marianas. The level of study of the diverse invertebrate groups is highly variable (e.g., Benbow et al. 2001).

- *Vertebrates*- Native vertebrate species include amphidromous fish, discussed above, estuarine fish which reproduce on reefs, waterbirds, and reptiles. Native fish and reptile numbers tend to increase from east to west. Hawaii has no native non-marine reptiles or amphibians. Endemic and indigenous wetland bird species and subspecies are present in all island groups. Birds have been well-studied in all regions. Fish have been studied in Hawaii, but less is known about species in the Western Pacific.
- *Fungi*- Some study has been done on aquatic fungi in Hawaii, but comparatively little is known elsewhere in the PACN.

Native non-aquatic predators

Birds and lizards are the only terrestrial native predatory groups in freshwater Pacific Island environments. In Hawaii, no native land reptiles or mammals (except the Hawaiian hoary bat; *Lasirus cinereus semotus*) existed prior to human arrival. The situation on other Pacific Islands was somewhat different; American Samoa, for example, had several native geckoes and skinks, as well as a boa, and Guam and Saipan had several native geckoes, skinks and a monitor lizard. This situation is significantly different today, with many of the native birds extinct, the Samoan boa and several of the Marianas lizards rare, and predators such as the Brown tree snake (*Boiga irregularis*, on Guam and Saipan), Indian mongoose (*Herpestes auropunctatus*, in Hawaii), and feral cats (*Felis silvestris*) and dogs (*Canis familiaris)* consuming aquatic and semi-aquatic fauna. External predatory pressures on aquatic species are now much higher than they were prior to human colonization.

Alien species

The introduction of alien invasive species is perhaps the most significant threat to the maintenance of native freshwater systems, second only to dewatering. It is important to distinguish between island groups when categorizing a species as native or alien. For example, Red mangrove (*Rhizophora mangle*) and the Tahitian prawn (*Macrobrachium lar*) are alien species in the Hawaiian islands, but indigenous to Samoa and the Marianas Islands. The stream and wetland ecological models contain detail on the ecological effects of alien invasive species.

Indicator Species

One of the primary goals of the Inventory & Monitoring Program is to identify species in National Parks that may be used as indicators of ecosystem health. These species are not necessarily recognized species of concern (which should also be monitored). Indicator species are species that are sensitive to environmental disturbance or those whose presence plays a large role in community structure.

Plants and algae- Plant communities are typically categorized by several characteristic species within the community. These characteristic species may be useful as indicator species. The community composition of freshwater algae, which responds quickly to changes in nutrient levels, is often used in water quality monitoring to indicate ecosystem health, although this has been done to a limited extent in the Pacific (e.g., Zolan 1981, Stephens 2003).

Invertebrates- Several species of freshwater and anchialine shrimp are native to Pacific Island groups and may be useful as indicators. For example, several anchialine pool species in Hawaii are restricted in distribution and appear to be highly sensitive to anthropogenic disturbance. \`Opae\`ula (*Halocaridina rubra*), the most common species of anchialine shrimp, may not be useful as an indicator species because it has a wide range of environmental tolerance. The endemic Hawaiian damselfly genus *Megalagrion* contains 22 species and 3 subspecies which are sensitive to environmental disturbance, especially pollution and predation by alien fish; several species have been extirpated from part or all of their native ranges (Polhemus & Asquith 1996). Other insect groups in Samoa and the Marianas may also be suitable as indicator species. Several snail species are present in freshwater habitats. These include lymnaeid snails in seeps and streams and neritid snails in anchialine pools and streams. Lymnaeid snails are confined to freshwater systems, while neritid snails have a marine larval stage. Some mollusks are sensitive to environmental disturbance, and are often utilized as indicator species (e.g., Anthony et al. 2004).

Amphidromous fish- Fish species such as gobies (Hawaii, Samoa, Guam, and Saipan) and freshwater eels (Hawaii & Samoa) may also serve as indicator species. The presence of healthy populations of amphidromous fish indicates good aquatic habitat and the maintenance of aquatic connections to the ocean.

Stream Biology Conceptual Model

Streams on Pacific Islands may be perennial (flowing to the sea all year), intermittent (seasonally flowing), or interrupted (with lower reaches seasonally dry, but always having water in their upper reaches)[23] (Polhemus et al. 1992). Perennial flowing springs and seeps (rheocrenes), which are differentiated from streams by having indistinct channels, will be discussed in the wetland conceptual model. Perennial streams or stream portions provide habitat to completely aquatic species, such as fish, algae, snails, and shrimp, while intermittent portions may be important as breeding habitat for insects and feeding areas for other fauna. Estuarine regions of Pacific Island streams tend to be fairly small, as compared to continental estuaries. However, they are important biologically as both a breeding ground and nursery for marine fishes and serve as a link between freshwater and marine environments for amphidromous species. They may be either marshy or rocky.

The extreme isolation of Pacific islands has resulted in a limited diversity of native species, but a high degree of endemism. As in many terrestrial plant and animal groups, freshwater native species richness generally declines and the degree of endemism increases with distance from a continent (Haynes 1988, Ford & Kinzie 1991, Font 2003). Because of the vast ocean distances separating freshwater habitats on different islands, freshwater Pacific island fauna have in many cases evolved from marine ancestors; marine stages in their life cycles allow these organisms to travel great distances across the ocean. Freshwater and brackish systems in the PACN are vulnerable to invasions of alien species, especially when natural environmental conditions have

[23] While the PACN defines a perennial stream as one which flows year-round to the sea, the State of Hawaii defines a perennial stream as one which has permanent water along at least part of its course (HCPSU 1990). Thus, several streams classified as perennial by the State of Hawaii are considered intermittent by the PACN.

been modified by human activity. Figure One illustrates the interconnections between model components.

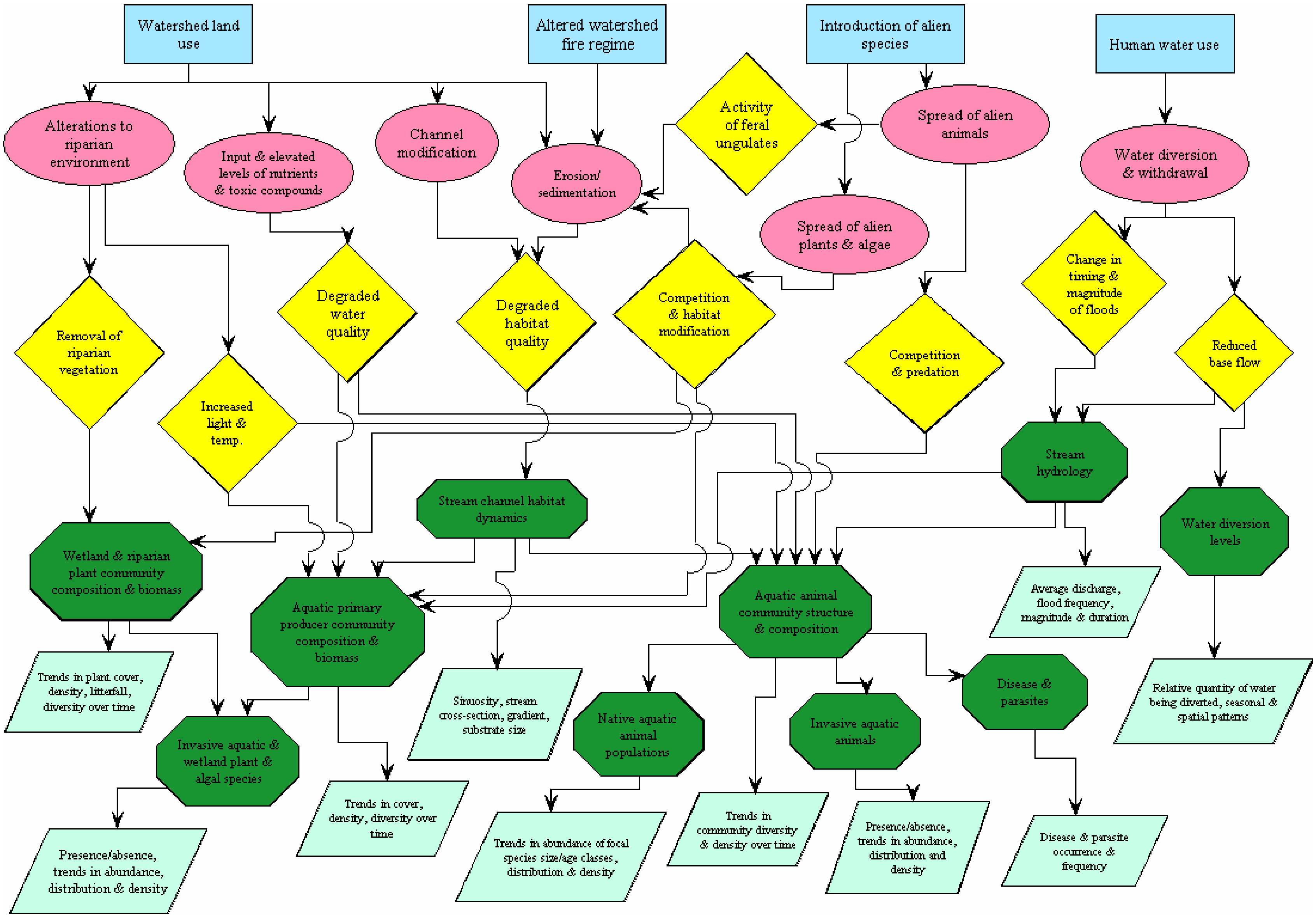

Figure 1: Stream biology conceptual model diagram, illustrating external drivers (rectangles), ecological stressors (ovals), effects of stressors (diamonds), ecological attributes (octagons), and ecological measures (parallelograms).

External Drivers and Ecological Stressors

Major external drivers of ecological stressors in Pacific Island stream ecosystems include **watershed land use, channel modification, altered watershed fire regime, introduction of alien species,** and **human water use.**

Changing land use practices in the islands, especially in low-lying areas, are rapidly altering instream habitats. These changes include increasing urbanization, groundwater and surface water withdrawal, stream channelization for flood control, increased frequency of forest or grassland fires, and clearing of riparian areas for agriculture and urban growth. Land use also affects water quality, resulting in changes in nutrient levels, contaminant detections and concentrations, water flow, turbidity, sediment levels, and water temperature[24]. These changes make freshwater resources less suitable as habitat for native species, and may facilitate the spread of alien species that are able to out-compete native species in changed environmental conditions (Vitousek et al. 1996, Brown et al. 1999, Brasher 2003).

Alterations to Riparian Environment- Removal of riparian vegetation (as distinguished from aquatic or wetland vegetation) can have several effects. These include increased rates of erosion and siltation, which lead to changes in light penetration to the stream, increased temperature, changes in nutrient input and the amount of organic matter entering water bodies, and loss of bank stabilization (Gregory et al. 1991). Riparian vegetation degradation also has potential adverse pollution and sedimentation effects to nearshore waters and coral reef ecosystems throughout the Pacific Islands. In areas with heavy cover of alien plant species, the riparian community may also impact stream ecosystems, by adding additional detritus, changing algae species composition, and affecting the food sources for native fish (Sherwood & Kido 2002).

Input and Elevated Levels of Nutrients and Toxic Compounds- Nutrient levels can be influenced by many land use practices. These include human waste from sewage or septic tanks, animal waste from grazing, farming, or aquaculture operations and fertilizers from agricultural operations. Nutrients and pollutants can be transported into freshwater ecosystems either by surface or groundwater flow. Several parks have agricultural activity (e.g., animal grazing) or large numbers of cesspools or septic systems within watershed or park boundaries.

Toxic compounds include pesticides (such as those used for vector control or historical or current termite control), herbicides, petroleum products, and human or animal waste. There is the possibility of large-scale water contamination events from accidental chemical, petroleum, or sewage spills in several parks near urban or industrial-use areas.

Channel modification- Direct stream channel modifications include stream bed channelization and lining and the construction of dams, culverts, and diversion structures. Channel modifications can completely eliminate suitable habitat for native aquatic species and facilitate the invasion of alien species (Brown et al. 1999, Brasher 2003).

Erosion and Sedimentation- Deposition of sediment within streams leads to alteration of benthic habitat. Filamentous benthic freshwater algae, which are utilized as a food source by native freshwater fish and mollusks and as habitat for some native insect larvae, generally require a rocky substrate on which to grow. Sediment deposition leads to changes in substrate from rocky to muddy, depriving filamentous algae of colonization sites. Suspended sediment in

[24] For a more detailed discussion of water quality-related issues, see the Water Quality workgroup report in Appendix A.

the water column also limits the amount of light available to submerged photosynthetic organisms, thereby retarding their growth (Allan 1995).

Sedimentation results from upstream erosion caused by clearing vegetation, fires, development, and agriculture upslope from streams or drainage areas, or from upslope activity of feral ungulates. Sediments generated from agricultural or urbanized areas may carry pollutants such as herbicide or pesticide residues or toxic metals. These pollutants may settle on pond bottoms or in wetlands, and be ingested by aquatic animals. Several groups of pollutants accumulate in tissue, and their effects are magnified as they move up the food chain (Brasher & Anthony 2000).

Spread of Alien Plants and Algae- Many aquatic and semi-aquatic vascular plants and marine or brackish algae have been identified as invasive species on Pacific islands. Wetland and riparian areas are at high risk for invasion of weedy plants, which may alter the structure of vegetation communities to such an extent that aquatic habitat also becomes altered and native species (both plant and animal) can no longer exist there. Many rapidly-growing alien plant species are either adapted to low-lying wetland environments or prove very successful in them. Examples of this include several grass species, network-wide, and mangrove (*Rhizophora mangle* & *Brugueira gymnorrhiza*) in Hawaii. Mangrove invades both coastal marine and freshwater habitats and alters water flow and sediment retention in these areas (Allen 1998). However, several mangrove species are native to Guam, Saipan, and Samoa, where they are a dominant component of mangrove wetlands, which are considered threatened habitats worldwide.

Both macroalgal and microalgal (unicellular) floras of some Pacific islands have been surveyed for species diversity. It may not be possible to tell whether algal species currently present are native or introduced, as extensive collections of freshwater algae were not conducted until relatively recently (e.g., Sherwood 2004). In brackish areas, such as fishponds, estuaries, and anchialine pools, the potential also exists for invasion by macroscopic alien marine species, which is recognized as a large concern in marine areas (e.g., Smith et al. 2002).

Spread of Alien Animals- Nearly all Pacific Island streams are affected to some degree by either aquatic or terrestrial alien invasive animals. Terrestrial animals include feral ungulates and vertebrate and invertebrate predators (insects, reptiles, and mammals). Aquatic animals include both vertebrates (fish and amphibians) and invertebrates (shrimp, snails, and insects).

In the PACN, several dozen introduced freshwater invertebrate species are known. These include insects (e.g., a caddisfly, *Cheumatopsyche pettiti*), mollusks (e.g., apple snail, *Pomacea canaliculata*), and arthropods (e.g.,Tahitian prawn, *M. lar*, which is introduced to Hawaii but native to Guam, Saipan, and Samoa). A large number of aquatic and riparian insect species have been introduced (State of Hawaii 2003). These species may compete with native species for resources such as space or food or prey upon them. The introduced carnivorous terrestrial snail *Euglandina rosea*, which has had a devastating impact on endemic Hawaiian tree snails (Cowie 1998), has been observed entering water to prey upon native aquatic snails (Kinzie 1992). Several introduced mollusks and invertebrate species have been identified as indicators of degraded water quality in streams by the National Water Quality Assessment Program (NAWQA) program on the island of Oahu (Anthony et al. 2004).

Introduced aquatic vertebrates include fishes and amphibians; these species may compete with, prey upon, or introduce parasites to native species. Introduced terrestrial species such as pigs (*Sus scrofa*) and goats (*C. hircus)* can cause damage through erosion, physical trampling, riparian vegetation removal, and pollution. In addition to causing erosion, feral animals in watersheds, especially pigs (*S. scrofa)* and rats (*Rattus* spp.), may spread disease, such as leptospirosis. Introduced species may also prey upon wetland birds and chicks (e.g., Brown tree snake (*B. irregularis)*, large fish, Indian mongoose (*H. auropunctatus)*, and cats (*F. silvestris)*) (Stinson et al. 1991, Morin 1998).

Water Diversion and Withdrawal-Diversion of surface water for agriculture and industry and withdrawal of groundwater for human consumption is one of the most significant stressors to freshwater biota on Pacific Islands. Water diversion reduces base flow in streams, thereby decreasing habitat availability, flow velocity, and channel size (Brasher 1997b). Other effects of stream diversion include dampening of both the frequency and magnitude of periodic flooding events (Brasher 1997b). In the Hawaiian Islands, long term downward trends in base flow of streams have been observed, suggesting that groundwater withdrawal is having a deleterious effect on surface water resources (Oki 2004). The degree of water diversion and groundwater withdrawal varies from island to island and park to park.

Ecological Attributes

Note: The ecological attributes included in the current stream biology conceptual model are primarily the set of Vital Signs proposed for monitoring stream ecology. As Vital Signs selection proceeds, this conceptual model will be somewhat simplified.

Wetland and Riparian Plant Community Composition and Biomass

The riparian plant community is an integral part of a stream system. The riparian community controls the amount of light reaching the stream surface, and strongly influences nutrient cycling and transport, organic matter input, bank stability and stream channel morphology, and subsurface water flow into a stream (Gregory et al. 1991). Historically, low-lying Pacific Island wetland, riparian, and coastal areas were the first to be altered by human activities; therefore communities in these areas have often been significantly altered (e.g., Burney et al. 2001).

Aquatic Primary Producer Community Composition and Biomass

With the exception of aquatic mosses, most native freshwater higher plants on Pacific Islands are emergent or riparian species. Algae comprise a significant proportion of the diet of several native fish species (e.g., Kido et al. 1993, Kido 1997). Community composition and biomass of algae and aquatic plants are often used as water-quality indicators (e.g., Zolan 1981), and algal remains may also be used to discern patterns of climate change in lakes and wetlands (such as temperature or salinity changes). Blooms of filamentous or microscopic algae can deplete oxygen in slow-moving stream segments and contribute to fish kills; this is rare in PACN streams and only occurs in highly modified streams.

Invasive Aquatic and Wetland Plant and Algal Species

Alien plant and algal species can serve as important indicators of ecosystem health. Invasive plant and algal species can impede water flow (filamentous algae and grasses), increase sediment deposition (mangrove and grasses), change patterns of organic matter input (fruit-bearing or nitrogen fixing plants), exclude sunlight, exclude native plants and algae, change dissolved oxygen levels in water, and provide an inferior food source for aquatic herbivores.

Aquatic Animal Community Structure and Composition

Most native Pacific island stream fish and some macroinvertebrate species have an amphidromous life history, in which an adult attaches eggs to or underneath rocks in a stream. Larvae hatch and are washed downstream, and spend several months maturing as part of the marine plankton community (Radtke & Kinzie 1991). Juveniles then recruit back to a stream and mature. Amphidromous species include gobies (e.g., *Stenogobius* spp., *Awaous* spp.), some freshwater shrimps and prawns (e.g., *Atyoida* spp., *Macrobrachium* spp.), and neritid snails (March et al. 2003). Some Pacific island fish species have a catadromous life cycle, in which adults migrate to estuarine or marine habitats to breed, but live in fresh water. Catadromous species include freshwater eels (*Anguilla* spp.), flagtails (*Kuhila* spp.), and sleepers (Eleotridae) (March et al. 2003).

In contrast to salmonid species, which have a similar anadromous life history, Hawaiian stream fish can reproduce several times over the course of their lives, and do not necessarily return to the stream from which they were spawned. In several Hawaiian fish and invertebrate species, studies suggest that enough mixing occurs during the marine stage of their life cycle that communities in different streams are not very genetically differentiated from one another (e.g., Fitzsimons et al. 1990, Chubb et al. 1998, Hodges & Allendorf 1998). This is an important factor in maintaining populations in different streams; if, for example, one stream's population has poor breeding success one year, juveniles who were spawned in another stream may recruit to the less successful stream and come to maturity there. However, habitat maintenance in many streams is critical for the survival of these species. Reproduction is very low in some streams, so these may serve as "sinks" for individuals hatched in better-quality streams (e.g., Way et al. 1998). It is not known if this is the case in streams on other Pacific islands, and is an area of their biology that needs further study. A diagram illustrating the spatial element of the amphidromous life history is shown below (Fig. 2). The catadromous life history is similar, though adults return to estuarine or marine habitats to breed rather than remaining in upper reaches of streams.

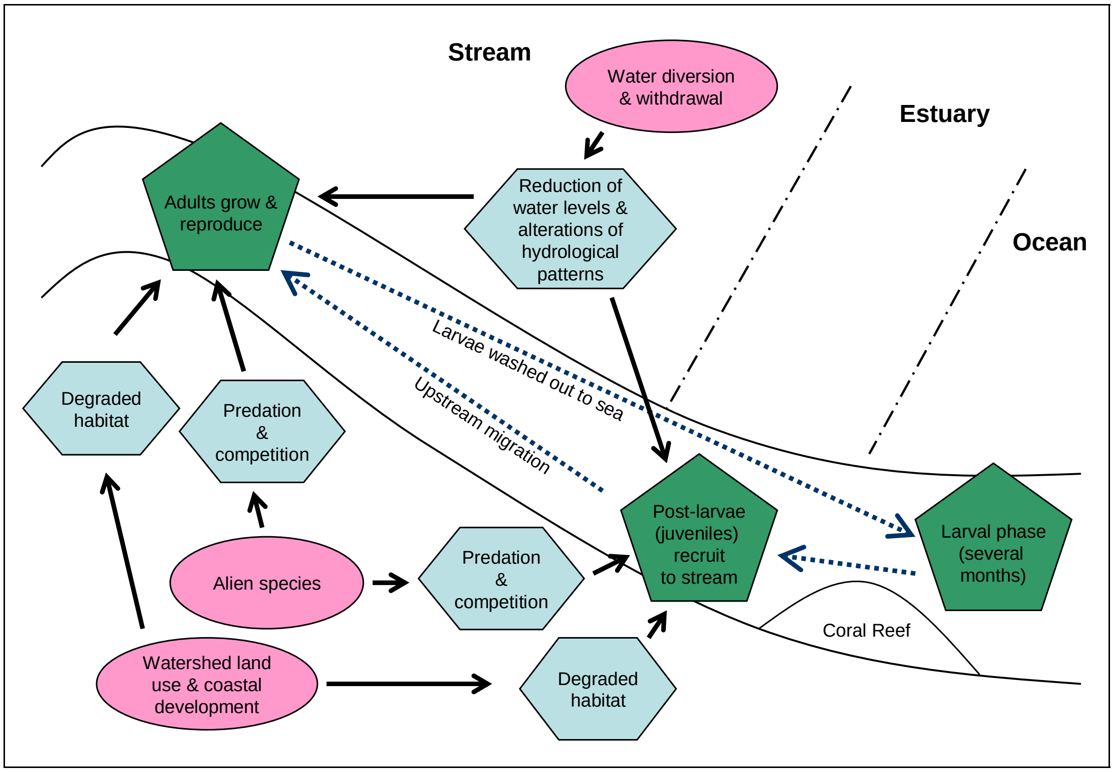

Figure 2: Amphidromy life history model, illustrating habitats in which life history stages occur (pentagons), potential anthropogenic disturbances (ovals), and effects of stressors upon organisms in each life history stage (hexagons).

Invasive Aquatic Animals

Alien animal species may also serve as indicators of ecosystem health, as they potentially have very serious impacts on native populations and ecosystems. Removal of invasive species is often a high priority, and in systems lacking invasive predators it is important to monitor aquatic areas for their presence in order to detect their establishment as soon as possible. The establishment of a variety of invasive animals can have different consequences for native communities, depending on such factors as the invasive species' behavior and feeding and habitat preferences. For example, tilapia (*Oreochromis*, *Sarotherodon*, and *Tilapia* spp.) are known as voracious predators on aquatic insects and fish, while armored catfish (*Hypostomus* sp.) compete for food resources with native fish and contribute to bank erosion (Yamamoto & Tagawa 2000).

Invasive aquatic species can either prey upon or compete for food with natives. An example of this is the introduction of surface-feeding topminnows (Poecilids), which have a profound predatory impact on native aquatic insect larvae, in contrast to bottom-feeding native gobies (Englund 1999). Conversely, the introduction of alien prey species can alter the diet of native predators (Kido et al. 1993). The introduction of invasive aquatic species can also have indirect effects such as the introduction of parasites or alteration of habitat.

Native Aquatic Animal Populations

Focal or indicator species, including those with ecological significance, those with legally-recognized threatened status, and those which individual parks have recognized as being worthy of monitoring (e.g., culturally significant species) can be monitored at a more intensive level than the rest of the aquatic community. These species will be selected as is appropriate to the particular aquatic systems. For example, both the mollusk *Neritina granosa* (hihiwai) and fish *Sicyopterus stimpsoni* (`o`opu nopili) are considered indicators of good stream habitat in Hawaii, while the fish *Lentipes concolor* (`o`opu alamo`o)was previously a candidate for listing as an endangered species. Insects are frequently sensitive to environmental disturbances, especially pollution and predation, and several insect groups might be suitable as indicator species.

Disease and Parasites

Parasite and disease levels are indicators of the health of aquatic populations. Introduced fish in Hawaii have been shown to carry parasites such as leeches or diseases that may be transmitted to native stream fish. These introduced parasite species often have greater impacts on native Hawaiian fish than native parasites do, due to differences in their life cycles (Font 2003). The prawn *M. lar* (introduced to Hawaii, but native to the other island groups in the PACN) likely transmitted the “black spot” disease to shrimp on Oahu (Eldridge 1994). This is an issue of unknown magnitude on the other islands in the PACN, though fewer parasite species have been found in situations with fewer alien fish introductions. The introduction of mosquitoes (*Culex* spp.) to freshwater habitats has had wide-ranging effects on both human and avian health; different species spread diseases such as avian and human malaria, dengue fever and West Nile virus.

Stream Channel Habitat Dynamics

Stream channel habitat dynamics encompasses multiple scales, from watershed (10^4-10^5 m) to reach (10-10^2 m) to individual rocks or gravel bars (< 1-1 m). Streams are dynamic systems, and their channel topologies and substrates are naturally constantly changing. Stream channels are often modified by human activities such as damming, flood control, bank stabilization, or nearby agriculture. Modification of natural stream habitat often facilitates invasion by invasive alien species (Brasher 2003).

Stream Hydrology

Stream hydrology includes both base flow levels (which can vary seasonally or interannually) and extreme high flow events. Pacific Island streams typically have frequent and unpredictable periods of high flow associated with rainfall (e.g., Oki & Brasher 2003). These flooding events can be hazardous to human life, but are important to the maintenance of populations of native species (Nishimoto & Kuamoo 1997). Natural flow regimes are one of the fundamental driving components of stream and river ecosystems (Baron et al. 2002, Naiman et al. 2002).

Water Diversion Levels

Levels of water diversion serve as a hydrological indicator of ecosystem health. As human populations on Pacific Islands grow and increase their consumption, the level of water diversion increases. Water diversion affects stream hydrology, habitat quality, and structure of algal, plant, and animal communities, and is a major threat to stream and river ecosystems worldwide (Baron et al. 2002, Naiman et al. 2002).

Ecological Effects

In this model, ecological effects are the working hypotheses of the links between environmental stressors and ecological attributes. The level of certainty for each of these hypotheses varies. Further research on some of these linkages needs to be done; suggested research topics are listed in the next section.

Wetland and Riparian Plant Community Composition and Biomass

Relationship of wetland and riparian plant community to alterations in riparian environment

Alteration of the riparian environment directly affects wetland and riparian plant communities by the removal of vegetation. In shaded tropical streams, leaf litter or fruits may account for most of the primary productivity, and removing this source significantly affects pathways of nutrient transport within the stream. Species composition of nonnative vegetation may shade out light for algal growth or may change the course or geomorphology of the stream.

Level of certainty- High

Relationship of wetland and riparian plant community to spread of alien plants and algae

Wetland and riparian plant communities are altered when they are invaded by alien species. Alien plants can outcompete native species by monopolizing resources such as space, light or nutrients, or excreting toxic compounds which prevent growth. Alien plants can also modify riparian habitat by changing the flow and direction of the stream system.

Level of certainty- High

Aquatic Primary Producer Community Composition and Biomass

Relationship of aquatic primary producer community to alterations to riparian environment

Riparian vegetation forms a canopy over the stream. Removal of this vegetation significantly increases the amount of solar radiation reaching the stream surface, allowing more light to be made available to algae, mosses, and other aquatic plants. Most perennial Pacific Island streams had a canopy in the past, but this is frequently removed by human activity. Additionally, the substitution of alien riparian plant species for natives may affect nutrient cycling, canopy closure, and subsurface water movement into the stream.

Level of certainty- High for canopy removal, low for changes in riparian community

Relationship of aquatic primary producer community to spread of alien plants and algae

Aquatic plant and algae communities are altered when they are invaded by alien species. For the most part, we are able to identify alien vascular plants in the PACN, but in many cases it is uncertain which non-vascular aquatic plants and stream algae are actually native due to the low level of study of these organisms in the past.

Level of certainty- Moderate

Relationship of aquatic primary producer community to nutrient and toxic compound input

Nutrient levels affect aquatic biota by enhancing growth of aquatic plants and algae. Algal blooms resulting from high nutrient levels may also deplete oxygen levels; in addition, algae may produce toxins that, at bloom densities, trigger fish die-offs. Changing nutrient levels can also alter the community composition of aquatic algae and plants (Hill 1996).

Level of certainty- Moderate for nutrients, low for contaminants

Relationship of aquatic primary producer community to stream channel habitat dynamics

Substrate type has a large effect on aquatic plant and algal biomass. It also influences what plant and algal species can grow at a site (Dudley & D`Antonio 1991). Filamentous benthic freshwater algae, which are utilized as a food source for native freshwater fish and mollusks and as habitat for some native insect larvae, generally require a rocky substrate on which to grow. Sediment deposition leads to changes in substrate from rocky to muddy, depriving filamentous algae of colonization sites. Suspended sediment in the water column also limits the amount of light available to submerged photosynthetic organisms, thereby limiting their growth (Allan 1995).

Level of certainty- Moderate

Relationship of aquatic primary producer community to stream hydrology

High flow events can scour rock surfaces, removing aquatic plants and algae. Water velocity also influences community composition and biomass of plants and algae (Stevenson 1990).

Level of certainty- High for biomass, moderate for community composition

Invasive Wetland and Aquatic Plant and Algal Species

Relationship of invasive plant and algal species to wetland and riparian plant community and aquatic plant community

The introduction and spread of alien plants and algae can lead to establishment of populations of alien species in streams and in riparian and wetland areas. The establishment of such species can significantly alter community structure.

Level of certainty- High

Aquatic Animal Community Structure and Composition

Relationship of aquatic animal community to alterations in riparian environment

Increased water temperature resulting from riparian vegetation removal can be stressful to aquatic animals. Native Hawaiian stream fish have a limited temperature range in which they can survive (Timbol & Maciolek 1978).

Level of certainty- High

Relationship of aquatic animal community to nutrient and toxic compound input

As with sediment-bound pollutants, soluble pollutants can accumulate in plant and animal tissue and enter the food chain (Brasher & Anthony 2000). The effects of contaminants on the health of stream animals are dependent on the type, concentration, and duration of exposure to the contaminant as well as the animal species, life stage, and tolerance range. Effects can be lethal or, more often, sub-lethal, affecting the animal's health and reproductive ability.

Level of certainty- High for some contaminants and moderate for others, low for nutrients

Relationship of aquatic animal community to stream channel habitat dynamics

Altered streambed conditions often lead to lack of appropriate habitat structure and increased temperatures, causing greater mortality of aquatic species from predation and heat shock. In channelized or otherwise modified streambeds, water temperatures frequently exceed the lethal limits for native species (Timbol & Maciolek 1978). Water flow is also important, as cool, highly oxygenated rapidly moving water is necessary for the survival of many stream-adapted species. Environmental changes may also trigger changes in competition and predation behavior of native aquatic species (Brasher 1997b).

Physical barriers to upstream or downstream migration severely reduce the survival rate of larvae and juvenile organisms. Flood-control structures, agricultural diversion dams or hydropower dams are examples. In many tropical island streams, altered channel conditions provide habitat ideally suited for alien species, which then form a physical "gauntlet" of predation that juveniles must run before passing upstream (March et al. 2003).

Level of certainty- High

Relationship of aquatic animal community to stream hydrology

Native stream fauna are adapted to periodic flooding. For example, stages of the amphidromous species' life histories may be cued to flooding events. These events also exclude many alien animal species from the upper reaches of streams which have natural flow regimes (Brown et al. 1999).

Evidence suggests that timing of spawning by amphidromous fauna is associated with high levels of stream flow (e.g., Way et al. 1997). It has also been hypothesized that recruitment of juveniles into streams is linked to high levels of discharge (Nishimoto & Kuamo`o 1997). The presence of healthy populations of amphidromous and catadromous fish indicates good aquatic habitat and the maintenance of aquatic connections to the ocean (e.g., March et al. 2003).

Level of certainty- Moderate

Relationship of aquatic animal community to spread of alien animals

Aquatic animal communities are altered when they are invaded by alien aquatic species. Alien terrestrial species can also affect aquatic animal communities through predation (e.g., the predatory snail *E. rosea*) or habitat alteration (e.g., activities of feral ungulates).

Level of certainty- High

Invasive Aquatic Animal Species

Relationship of aquatic invasive animals to aquatic animal community

The introduction and spread of alien animals typically leads to establishment of populations of alien species in streams, changing the structure and composition of the aquatic animal community. The presence of invasive aquatic animals indicates disturbance to the aquatic community, though some species have more of an impact upon the animal community than others.

Level of certainty- High

Native Aquatic Animal Populations

Relationship of native aquatic animal populations to aquatic animal community

Populations of native aquatic animals are influenced by the entire aquatic animal community. Populations of Pacific island fish species are known to frequently exhibit vertical zonation in distribution along the length of a stream (Fitzsimons et al. 2002, Cook 2004). Where populations coexist in a stream segment, different species may show different behaviors and feeding preferences (Kido 1997). The presence of alien species in a community can affect the relationships among native animals in multiple ways.

Level of certainty- High

Disease and Parasites in Aquatic Animals

Relationship of disease and parasites to aquatic animal community

Many of the significant diseases and parasites in Hawaiian fish are non-native, and were introduced via the introduction of alien animals. There is little information as to the degree to which this occurs in invertebrates and fish on other Pacific islands.

Level of certainty- Moderate in Hawaiian fish, low elsewhere

Stream Channel Habitat Dynamics

Relationship of stream channel habitat dynamics to erosion and sedimentation

Erosion and sedimentation both affect habitat availability to aquatic plants and animals (Allan 1995). Sedimentation can be increased by the introduction of alien plants, such as grasses or mangroves (which are only alien in Hawaii). Sediment retention within a stream channel can be reduced by the removal of aquatic plants. Bank erosion is also increased when feral ungulates are introduced, thus a relationship also exists between stream channel habitat dynamics and spread of alien animals.

Level of certainty- High

Relationship of stream channel habitat dynamics to channel modification

Pacific island streams characteristically have highly heterogeneous, boulder-strewn channels, with a diversity of habitat types. Channel modification removes this natural, spatially variable, habitat. Lining a stream channel with concrete for flood control commonly creates a U-shaped channel with a broad, flat bottom and steep walls. The results of such modification are a wide, shallow water course with no topographic variation. Stream channel lining has been observed to cause increased water temperature, pH, and dissolved oxygen due to increased photosynthetic activity, and a decrease in nitrate uptake due to the lack of a natural sediment-dwelling microbial community (Laws & Roth 2004).

Level of certainty- High

Stream Hydrology

Relationship of stream hydrology to water diversion and withdrawal

Two effects of water diversion and withdrawal on stream hydrology exist: flood duration, frequency, and intensity may be reduced; and base flow may be reduced. Seasonal differences in stream flow are dampened and extremely low flow conditions are increased by water withdrawals (Way et al. 1997).

Level of certainty- High

Water Diversion Levels

Relationship of water diversion levels to water diversion and withdrawal

Measurement of relative levels of water diversion will indicate the impact of human water withdrawals on stream systems.

Level of certainty- High

Research Questions

Relationship of aquatic animal community to available food sources

Studies in Hawaii suggest that several native fish are opportunistic feeders that will utilize algae and both native and alien insects. What is the effect of changes in food availability on native aquatic animal communities in other island groups? Do feeding preferences of aquatic animals significantly affect the structure of aquatic primary producer communities?

Effect of parasites and disease on native stream animals

Many fish parasites in Hawaiian streams have been shown to be introduced. To what degree do parasites and disease affect native fish in the rest of the PACN? Are parasites and diseases native, or were they introduced along with alien species? Is there a relationship between alien fish density and parasite loads? What are the levels of disease and parasitism on aquatic invertebrates?

Relationship of riparian plant communities to instream processes

Riparian plant communities in the PACN are often highly modified. Where riparian plant communities do exist, what effects does the replacement of native plant species with alien species have on nutrient cycling, shade patterns, organic matter input, and subsurface water flow into the stream? In turn, how do these processes affect patterns of instream primary and secondary productivity?

Relationship of aquatic primary producer and consumer communities to water quality

Which nutrients most limit aquatic primary productivity? What effect do specific contaminants have on primary producers and consumers?

Relationship of groundwater withdrawal to stream flow

Groundwater withdrawal is increasing on Pacific islands for human consumption, especially as populations continue to grow. What is the relationship between groundwater withdrawal and base flow of streams?

Ecological Measures

Ecological measures in this model are equivalent to measures of the condition of proposed Vital Signs.

Table 1: Ecological measures of stream ecosystem attributes.

Ecosystem Attribute	Ecological Measures
Wetland and Riparian Plant Community Composition and Biomass	Trends in plant cover, density, litterfall, and diversity over time.
Aquatic Primary Producer Community Composition and Biomass	Trends in cover, density, and diversity over time.
Invasive Wetland and Aquatic Plant and Algal Species	Presence or absence, trends in abundance, distribution, and diversity.
Aquatic Animal Community Structure and Composition	Trends in community diversity and richness over time.
Invasive Aquatic Animal Species	Presence or absence, trends in abundance, density, distribution, and diversity.
Native Aquatic Animal Populations	Trends in abundance of focal species size and age classes, distribution, and density.
Disease and Parasites in Aquatic Animals	Disease and parasite occurrence and frequency.
Stream Channel Habitat Dynamics	Sinuosity, stream cross-section, gradient, and substrate size.
Stream Hydrology	Average discharge, flood frequency, magnitude, and duration.
Water Diversion Levels	Relative quantity of water being diverted or withdrawn. Includes seasonal, temporal, and spatial patterns.

WETLAND BIOLOGY CONCEPTUAL MODEL

Several different types of wetlands exist on Pacific Islands. These include freshwater and saline lakes, ponds and reservoirs, high-elevation bogs, marshes, and swamps, lowland seasonal playas, lowland freshwater marshes and swamps, and lowland salt marshes, swamps (including mangrove forests), and anchialine pools (Polhemus et al. 1992).

Coastal marshes and mangrove forests are brackish, and are usually tidally influenced to some degree. On the coast in Hawaii, mudflats, anchialine ponds, estuarine wetlands, and freshwater wetlands behind beach berms have been created over time. In the Marianas Islands and

American Samoa are found coastal and estuarine marshes, *Pandanus* spp. and native mangrove swamps. Mangroves are native to Saipan, Guam, and Samoa, but not the Hawaiian Islands.

In the United States, anchialine pool ecosystems are unique to the Hawaiian Islands (Maciolek 1987); the majority of pools are found on the west coast of Hawaii Island (Brock 1985). Anchialine pools function as surface “windows” into brackish groundwater systems that may extend for long distances. They are tidally influenced: water levels rise as the tide comes in and fall as it goes out, though there is a time delay depending on the distance to the ocean and directness of the subsurface connection to the ocean. Some pools are only visible on the surface during high tide. Species that live in these systems are classified broadly by whether they require sunlight for survival; one group does not require light, and can live within the system of brackish water underlying shoreline areas, while the other group is restricted to open pools. Anchialine pools are considered “special aquatic sites” under the Clean Water Act and offered the same kind of regulatory protections as wetlands.

Fishponds are Hawaiian man-made coastal structures with brackish water, used in the past for farming of marine and estuarine fish species. Most fishponds were constructed in coastal areas with varying degrees of freshwater input from streams and springs. They are an example of a resource with shared natural and cultural value; many fishponds have fallen into disuse with changes in subsistence patterns, but there is a high level of interest in restoring several of the ones in PACN parks.

Mid- and high-elevation marshes and bogs generally form in places where there is high rainfall, soils are poorly drained, or the volcanic geology has created aquitards or slope wetlands influenced by groundwater. These wetlands often are home to rare or endangered plants, insects, other invertebrates, and birds. Two types of inland ponds and lakes are found within PACN parks: high-elevation ponds associated with bogs in HALE, and a partially saline crater lake in KALA which has the highest depth to surface area ratio of any lake in the world (Donachie et al. 1999).

Smaller freshwater features in PACN parks include springs and seeps. Springs and seeps can be present at any elevation, and may be formed by aquitards in upland areas or intersections of land surface with the groundwater table in coastal areas. Due to the dynamics of groundwater lenses, freshwater springs are common in coastal areas just under sea level. Upland springs and seeps serve as important breeding grounds for endemic insects and snails. Springs and seeps can be important cultural resources, especially in arid regions.

For brevity, this conceptual model addresses all non-flowing surface water habitats found within parks in the PACN. It also includes perennially flowing springs and seeps which, though flowing, lack the defined channels of streams (Polhemus et al. 1992). This model groups PACN wetlands roughly into two groups: coastal wetlands, which are influenced by saline surface or groundwater, and inland wetlands, which are fed only by rain and fresh groundwater. Conceptual differences between these categories are noted in the text, and the conceptual diagram (Figure 3) illustrates these distinctions. In cases where model components are substantially similar to components in the stream biology model, the stream biology model is referenced.

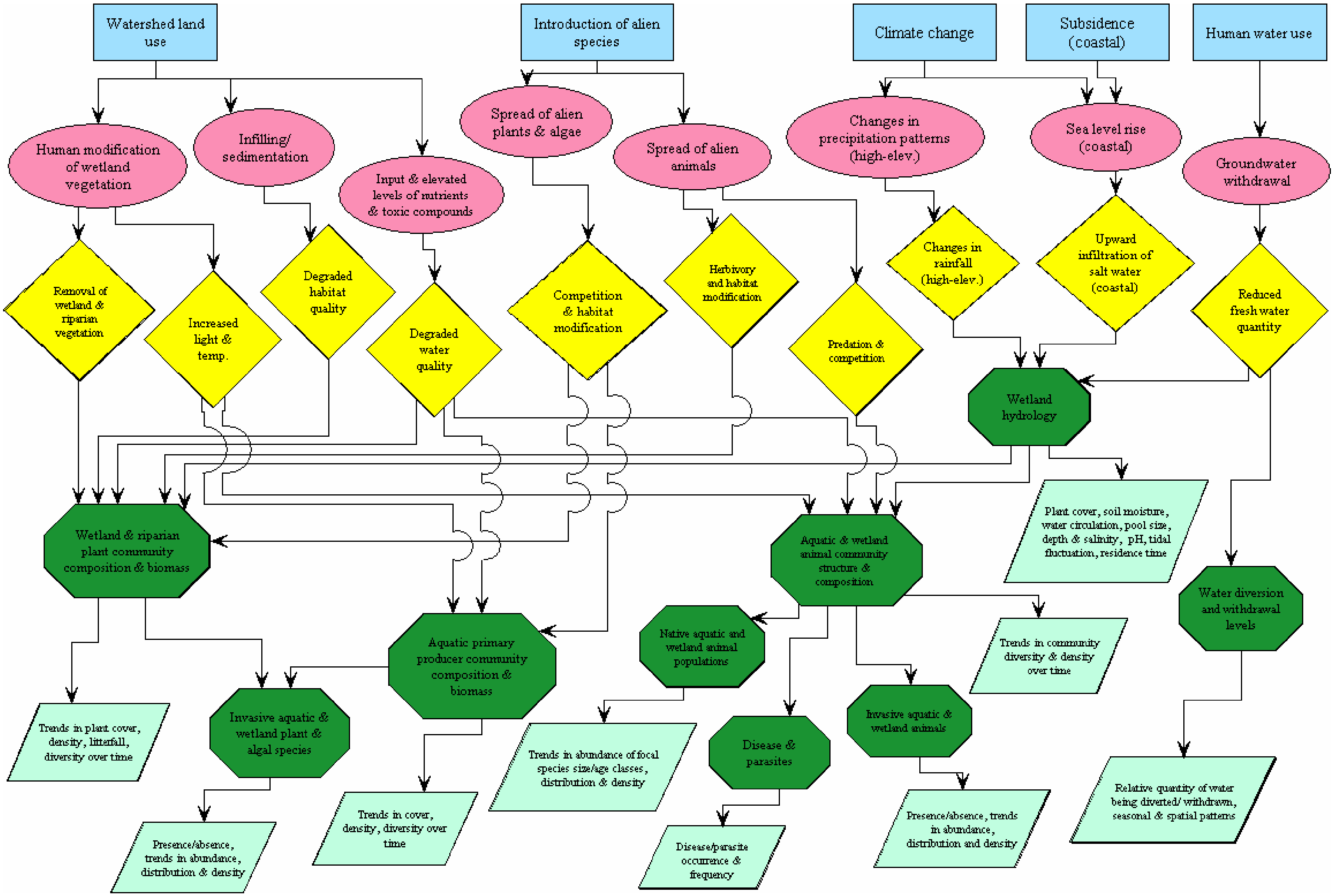

Figure 3: Wetland conceptual model diagram, illustrating external drivers (rectangles), ecological stressors (ovals), effects of stressors (diamonds), ecological attributes (octagons), and ecological measures (parallelograms). "Coastal"=affecting primarily coastal ecosystems, "high-elev."= affecting primarily high-elevation ecosystems.

External Drivers and Ecological Stressors

Major external drivers of ecological stressors in Pacific Island wetland ecosystems include **watershed land use**, **introduction of alien species, climate change, subsidence** (for coastal wetlands), and **human water use**.

Human Modification of Wetland Vegetation- Direct human modification of wetland vegetation, especially in lowland areas, has been occurring on Pacific Islands since initial settlement. Wetlands were traditionally modified for taro, rice, and grazing for agriculture and for aquaculture, and more recently for housing, urban and resort development, and dumping. Effects of riparian and aquatic vegetation removal streams are discussed in the stream biology model. These effects differ somewhat in aquatic habitats such as pools and ponds, because while in flowing streams they influence everything downstream and are diluted by moving water, ponds and lakes are directly affected with no dilution. This may be called the difference in "transport".

Infilling and Sedimentation- The causes and effects of erosion and sedimentation on aquatic flora and fauna are similar to those discussed in the stream biology model, though there are organisms unique to wetlands which are also affected (e.g., waterbirds, sedges). Erosion may be caused by human activity, activity of terrestrial or aquatic animals, rainfall, or wind. Sedimentation changes habitat availability for aquatic organisms and limits photosynthesis.

In addition to the effects of soil erosion and sedimentation, riparian vegetation can increase litter into aquatic habitats, or change patterns of soil retention. Excess plant litter from invasive species can fill pools and wetlands and decompose, depleting oxygen levels. Sedimentation and litterfall accelerate the natural rate of wetland succession, during which pools fill with sediment and evolve into dryer habitats. While succession is a natural process, its acceleration destroys existing ecosystems faster than new ones are created elsewhere, reducing habitat available for native organisms (Maciolek & Brock 1974, Chai et al. 1989).

Input and Elevated Levels of Nutrients and Toxic Compounds- The stream biology conceptual model discusses the effects of this stressor on surface waters. As with other water quality stressors, nutrients and toxic compounds concentrate in wetlands, lakes, and pools, rather than being diluted downstream. Nutrient inputs can have a dramatic effect on ponds and lakes, changing chemical, dissolved oxygen, and algae composition quickly. The effect of groundwater contamination on wetlands is also a concern in parks with urban and industrial areas sharing park aquifers, particularly KAHO (Jackson & Rosenlieb 1989).

Spread of Alien Plants and Algae- This stressor is discussed in detail in the stream biology conceptual model; however different types of plants, such as water lettuce (*Pistia stratiotes*), duck weed (*Lemna* spp.*)*, and *Salvinia* occur in wetlands and ponds; these plants affect biodiversity differently than in streams (e.g., they affect waterbirds). Also with isolated ponds, lakes, and wetlands, spread of aliens is more preventable than in streams- plants need to be planted or brought in by animals.

Spread of Alien Animals- The stream biology conceptual model has an in-depth discussion of this stressor; however wetlands are affected somewhat differently by the spread of alien animals. As with the spread of alien plants, the spread of alien aquatic animals is more preventable in isolated wetlands. For example, traditional uses of Hawaiian anchialine pools included use of pools as bait stocking areas for coastal fishing, however, native fish species traditionally stocked were not able to complete their life cycles within the pools, therefore the impacts on native invertebrates may have been smaller than those resulting from more recent stocking of freshwater-reproducing baitfish (e.g., tilapia [*Oreochromis*, *Sarotherodon*, and *Tilapia* spp.] and guppies and topminnows [poecilids]).

Wetlands are also directly affected by the spread of terrestrial animals, including both predators (e.g., Brown tree snake [*B. irregularis*], cane toads [*Bufo marinus*]) and herbivores (e.g., feral pigs [*S. scrofa*], mallards [*A. platyrhynchos*]).

Sea Level Rise- As young volcanic hotspot islands such as Hawaii and Maui grow, they slowly depress the oceanic plate on which they rest. This process leads to a slow subsidence of the islands relative to sea level. Low-lying costal freshwater resources such as wetlands, pools, and fishponds are heavily impacted by the resulting sea level rise. Even small levels of sea level rise may cause enough upward infiltration of saline water into groundwater to significantly increase salinity in anchialine pools and coastal wetlands, rendering these habitats unsuitable for freshwater biota. Sea level rise caused by global warming will cause similar effects even where natural subsidence is not occurring. Coastal freshwater and brackish systems are also severely affected by high waves and flooding associated with storms, which are predicted to increase in intensity, and possibly frequency, with global climate change (IPCC 2001).

Changes in Precipitation Patterns- Global climate change is predicted to cause several types of changes in patterns of precipitation that may significantly affect high-elevation wetlands and lakes, which are located near the trade-wind inversion and cloud lifting level. Geological and paleontological evidence suggests that the trade-wind inversion level on Hawaii and Maui has shifted significantly several times during the last 160,000 years in response to Ice Age events. It is uncertain whether the trade-wind inversion layer and its attendant patterns of cloud cover and rainfall will shift upwards or downwards with a warmer ocean, but it seems likely that some type of shift will occur (Loope & Giambelluca 1998). Interannual patterns of rainfall are also expected to become more variable as a result of global warming, and droughts are likely to become more frequent. High-elevation bogs and lakes on Pacific Islands are fed by precipitation, so this type of climate change could drastically reduce these ecosystems in size or eliminate them.

Water Diversion and Groundwater Withdrawal- Many wetlands are dependent on groundwater, including those in coastal areas where wetlands have formed from groundwater seeping from the base of the mountains then dammed by beach berms. Excessive withdrawal of groundwater can lower the water table, causing brackish wetlands to become more salty and freshwater wetlands to shrink in size or dry up. Isolated bogs and wetlands in high elevations can also be affected by groundwater withdrawals. Surface water diversion affects stream-associated wetlands in lower and higher elevations.

Ecological Attributes

Note: The ecological attributes included in the current wetland biology conceptual model are primarily the set of Vital Signs proposed for monitoring wetland ecology. As Vital Signs selection proceeds, this conceptual model will be somewhat simplified.

Wetland and Riparian Plant Community Composition and Biomass

Wetlands are defined by duration and frequency of hydrology, which influences and creates hydric soils and hydrophytic vegetation. Wetland plant communities on Pacific Islands are varied, and include woody coastal swamp forest (e.g., *Hibiscus tiliaceus, Pandanus tectorius, Bruguiera gymnorhiza*), lowland marshes and swamps (e.g., introduced and native grasses and sedges), and mid- to high-elevation bogs and marshes (e.g., mosses, sedges, and grasses). Riparian plant communities are found in nearly all ecosystem types from coastal strand in low elevations to high-elevation bogs and wetlands. Native wetland plant communities on Pacific islands in general are recognized as threatened by development, invasive species, and other causes.

Aquatic Primary Producer Community Composition and Biomass

Aquatic primary producers include unicellular and multicellular algae, bacteria, and aquatic plants. Little is known about aquatic primary producers in Pacific Island wetlands. In lakes, ponds, and pools, the plankton community often comprises the dominant primary producers. See the stream biology conceptual model for a discussion of this ecological attribute.

Invasive Aquatic and Wetland Plant and Algal Species

Invasive plant species which have been identified as a concern on Pacific islands include: pickleweed (*Batis maritima*), mangroves (in Hawaii only; *R. mangle* & *B. gymnorrhiza*), *Pluchea* spp., and *Phragmites karka*. Several marine algal species are a concern for brackish wetlands, fishponds, and anchialine pools in Hawaii; these include *Acanthophora spicifera* and *Gracilaria salicornia*. See the stream biology conceptual model for a further discussion of invasive plants and algae.

Aquatic and Wetland Animal Community Structure and Composition

See the stream biology conceptual model for a discussion of community structure and composition of aquatic animals, including those found in open aquatic systems such as lakes and ponds. Brackish wetlands, fishponds, and anchialine pools provide habitat for marine species (see the Marine topical workgroup report for more information about these species). Anchialine pool communities differ from other aquatic communities, in that many organisms in them utilize both surface and subterranean habitats (Bailey-Brock & Brock 1993).

Wetland animal communities include insects and other arthropods, birds (passerines and waterbirds), snails, and reptiles (Hawaii has no native reptiles). Several species of endangered waterbirds and forest birds occur in PACN wetlands.

Invasive Aquatic and Wetland Animals

Invasive aquatic animal species affect wetland and lake ecosystems similarly to the way that they affect stream ecosystems; see the stream biology conceptual model for a discussion of this attribute. Invasive terrestrial animal species have the potential to affect native wetland species as well. For example, the Brown tree snake (*B. irregularis)* has decimated native bird and reptile populations on Guam, and has been sighted on Saipan (Uyehara 1997). Introduced carnivorous mammals, including shrews (*Suncus marinus)*, cats (*F. silvestris)*, dogs (*C. familiaris)*, Indian mongoose (*H. auropunctatus)*, and rats (*Rattus* spp.), are a significant threat to wetland birds. The introduced mallard duck (*A. platyrhynchos*) competes with the endemic Hawaiian duck (*A.*

wyvilliana) for food and habitat, and interbreeding between the mallard and the Hawaiian duck currently threatens to hybridize the native species to extinction.

Native Aquatic and Wetland Animal Populations

Native wetland animal species on Pacific Islands include both resident and migratory waterbirds and shorebirds and resident passerines, reptiles, land crabs, mollusks, insects, and spiders. Wetland populations of particular concern include endangered birds, mollusks, insects, shrimp, and plants. See the stream biology conceptual model for further discussion of this ecological attribute.

Disease and Parasites

Disease and parasites are a primarily concern for freshwater fish and waterbirds. For discussion of the effects of disease and parasites on fish, see the stream biology model. One disease of particular concern for waterbirds is avian botulism. Botulism is caused by a toxin produced by *Clostridium botulinum*, an anaerobic bacterium which can survive in spore stage in aerobic conditions (Rocke & Samuel 1999). Botulism outbreaks can decimate waterbird populations at a site (Morin 1996, Morin 1998, Rocke et al. 1999). Environmental conditions which favor botulism outbreaks are not fully understood, but water redox potential, temperature, and sediment organic matter composition appear to be factors (Rocke & Samuel 1999).

Wetland Hydrology

Wetland hydrology, especially in brackish or tidally-influenced wetlands, is an important factor in determining composition and structure of the biological community. Hydrology is broadly determined by frequency and duration of water at the site. Subsidence, changes in hydrologic flow, and rainfall affect wetland hydrology, typically at much more rapid time scales than changes in underlying geology. Maintenance of the natural range of variation of these processes is required to sustain wetland and lake ecosystems (Baron et al. 2002).

Water Diversion and Withdrawal Levels

Groundwater diversion levels on Pacific Islands are expected to increase sharply with continuing high levels of population growth, increased water consumption, and changing patterns of urbanization. Water withdrawal directly influences the hydrological integrity of groundwater or surface water-fed wetlands, and is a fundamental threat to the sustainability of these ecosystems (Baron et al. 2002). See the stream biology conceptual model for a discussion of surface water diversion.

Ecological Effects

Wetland and Riparian Plant Community Composition and Biomass

Relationship of wetland and riparian plant community to human modification of wetland vegetation

Human removal of vegetation alters the wetland or riparian community directly as well as provides a disturbed habitat which invasive alien plant species may be able to exploit more readily than native species. In situations where wetland habitat is severely degraded due to sedimentation or introduction of invasive plants, human management may be essential to restore wetland habitat (Stinson et al. 1991, Ritter & Savidge 1999).

Level of certainty- High

Relationship of wetland and riparian plant community to infilling and sedimentation

Infilling of wetland or open water habitats by sediment can alter habitat to the extent that it is unsuitable for native species (e.g., Ritter & Savidge 1999). Invasive alien species may be able to exploit such disturbed habitat and outcompete native species.

Level of certainty- High

Relationship of wetland and riparian plant community to nutrient and toxic compound input

This relationship is discussed in the stream biology conceptual model.

Level of certainty- Moderate for nutrients, low for contaminants

Relationship of wetland and riparian plant community to spread of alien plants and algae

This relationship is discussed in the stream biology conceptual model.

Level of certainty- High

Relationship of wetland and riparian plant community to spread of alien animals

Herbivorous animals may feed upon both adult vegetation and predate seeds, as well as contributing to sedimentation, bank destabilization, soil compaction, and vegetation trampling.

Level of certainty- High to moderate for different effects

Relationship of wetland and riparian plant community to wetland hydrology

The volume, residence time, and movement of water in a wetland, seep, or lake play a large role in determining the community composition and productivity of algae and plants. In coastal wetlands, the proportion of fresh to salty water and tidal fluctuations additionally influence community composition and productivity.

Level of certainty- Moderate

Aquatic Primary Producer Community Composition and Biomass

Relationship of aquatic primary producer community to human modification of riparian and wetland vegetation

See the stream biology conceptual model for a discussion of the relationship between riparian vegetation removal and the aquatic primary producer community.

Level of certainty- High

Relationship of aquatic primary producer community to nutrient and toxic compound input

See the stream biology conceptual model for a discussion of this relationship.

Level of certainty- Moderate for nutrients, low for contaminants

Relationship of aquatic primary producer community to spread of alien plants and algae

This relationship is discussed in the stream biology conceptual model.

Level of certainty- Moderate

Invasive Aquatic and Wetland Plant and Algal Species

Relationship of invasive plants and algae to wetland, riparian, and aquatic primary producer communities

This relationship is discussed in the stream biology conceptual model.

Level of certainty- High

Aquatic and Wetland Animal Community Structure and Composition

Relationship of aquatic and wetland animal community to human modification of wetland vegetation

Modification or removal of wetland and riparian vegetation can alter or destroy habitat and food sources for animals. Additionally, vegetation removal increases light penetration and water temperature. Wetlands often serve as nurseries for juvenile fishes, and the loss of wetlands can severely impact the fish populations that rely on them. Removal of wetland vegetation can negatively affect waterbird habitat by depleting cover, nesting materials, and food (Stinson 1991, Ritter & Savidge 1999). See the stream biology conceptual model for a discussion of the effects of riparian vegetation removal on aquatic animals.

Level of certainty- Medium

Relationship of aquatic and wetland animal community to nutrient and toxic compound input

See the stream biology conceptual model for a discussion of this relationship.

Level of certainty- Moderate for some contaminants and low for others; low for nutrients

Relationship of aquatic and wetland animal community to spread of alien animals

See the stream biology conceptual model for a discussion of the relationship between aquatic animal communities and alien animal species. Anchialine pool communities are significantly affected by the introduction of predatory alien fish species such as topminnows (Bailey-Brock & Brock 1993). Alien terrestrial species such as the Brown tree snake (*B. irregularis)*, bullfrogs (*Rana catesbeiana*), or mongoose (*H. auropunctatus)* can have significant effects on wetland animals such as birds.

Level of certainty- Medium

Relationship of aquatic and wetland animal community to wetland hydrology

Water circulation and residence time, freshwater-saltwater balance, and frequency of inundation and low-water events play an important role in determining the type of animal species that can reside in wetlands.

Level of certainty- Low

Invasive Aquatic and Wetland Animal Species

Relationship of invasive aquatic and wetland animals to aquatic and wetland community structure and composition

See the stream biology conceptual model for a discussion of this relationship.

Level of certainty- High

Native Aquatic and Wetland Animal Populations

Relationship of native aquatic and wetland animals to aquatic and wetland community structure and composition

This relationship is discussed in the stream biology conceptual model.

Level of certainty- High

Disease and Parasites in Aquatic Animals

Relationship of disease and parasites to aquatic and wetland community structure and composition

Avian botulism is a disease of primary concern for wetland birds in the PACN, as botulism outbreaks can rapidly devastate populations (Morin 1996, 1998). The triggers for botulism outbreaks are not well understood at this time (Rocke et al. 1999, Rocke & Samuel 1999), and very little research has been conducted on this topic on Pacific islands. Other diseases of concern for birds are avian malaria, which is prevalent at low elevations on Pacific islands, and West Nile virus, which has recently been reported on Maui (as of Sept. 2004). See the stream biology conceptual model for a discussion of the relationship between fish communities and disease and parasites.

Level of certainty- Moderate in Hawaiian fish and low in waterbirds and other groups

Wetland Hydrology

Relationship of wetland hydrology to sea level rise

Coastal wetland hydrology is dependant upon the interactions between fresh and saline groundwater and surface water. An increase in sea level will lead to increased salinity in these habitats, as well as an increased incidence of wave activity in these areas during storms or high wave events.

Level of certainty- High, although site-specific effect certainty is low

Relationship of wetland hydrology to changes in precipitation patterns

Other than stream or river-associated wetlands, wetlands within the PACN are fed by groundwater. However, changes in patterns of precipitation such as droughts can have a significant effect on these ecosystems. Montane bogs and ponds would be significantly affected by changes in rainfall which would result from a shift in the trade wind inversion level as predicted by current global climate change models (Loope & Giambelluca 1998).

Level of certainty- Low, as exact probable changes in precipitation patterns are unknown

Relationship of wetland hydrology to groundwater withdrawal

Brackish and anchialine systems are tidally influenced, and the importance of freshwater inputs to these systems lies in maintaining the balance between fresh and salt water. Groundwater withdrawals upslope can result in raising salinity during high tides, as well as shrinking the size of pools and wetlands during low tides. However, this relationship is not as straightforward as the relationship between surface water diversion and stream flow. Groundwater hydrology is not fully understood on Pacific islands, at least on younger substrates.

Level of certainty- Low

Water Diversion and Withdrawal Levels

Relationship of water diversion and withdrawal levels to groundwater withdrawal

Monitoring levels of water diversion and withdrawal allow prediction of the effects of human activity on groundwater-fed wetland habitats. However, groundwater dynamics are complex, and this relationship is not as straightforward as the relationship between water diversion levels and surface water diversion.

Level of certainty- Medium

Research Questions

Effect of invasive plant and animal species on wetland communities

Wetlands in the PACN (including anchialine pools, marshes and swamps) are known to be affected by multiple invasive species of plants and animals. While anecdotal information exists about these effects, very little quantitative research exists on Pacific islands. What are the effects of competitive interactions between native and alien species on the biotic community as a whole? How are patterns of nutrient cycling influenced by the establishment of invasive plant species? Which alien species, once established, fundamentally alter wetland ecosystems?

Native keystone species

Which native species, once extirpated, fundamentally alter wetland ecosystems? It has been hypothesized that the most common species of anchialine shrimp (*H. rubra*) acts as a keystone species in anchialine pool ecosystems. *H. rubra* removal (due to predation by introduced alien fish) is correlated with overgrowth of mat-forming algae by longer filamentous algae (Bailey-Brock & Brock 1993, Brock & Kam 1997), but rigorous testing of this hypothesis should be done. Do other, less common, anchialine pool shrimp species play a similar role?

Effect of sea level rise on coastal wetland hydrology

While the general effects of sea level rise on coastal wetlands are predictable (i.e., increased saltwater intrusion and wave action), site-specific effects are not. Which PACN wetlands are most at risk from sea level rise? What are possible mitigation strategies that will allow the preservation of species that live in these ecosystems?

Effect of climate change on the trade-wind inversion level

Increases in sea surface and air temperatures are predicted to occur as a result of global climate change. What will the effect of these changes be on the trade-wind inversion and cloud lifting levels? What will the effects of a shift in trade-wind inversion level be on the present high-elevation bogs and lakes?

Groundwater dynamics

While older Pacific islands have groundwater hydrology which is largely understood, younger islands have less-predictable groundwater dynamics. How does young volcanic geology affect movement of groundwater? How do groundwater dynamics affect movement of pollutants through groundwater and into aquatic systems? How will groundwater withdrawals affect wetland hydrology?

Ecological Measures

Ecological measures in this model are equivalent to measures of the condition of proposed Vital Signs.

Table 2: Ecological measures of wetland ecosystem attributes.

Ecosystem Attribute	Ecological Measures
Wetland and Riparian Plant Community Composition and Biomass	Trends in plant cover, density, litterfall, and diversity over time.
Aquatic Primary Producer Community Composition and Biomass	Trends in cover, density, and richness over time. Includes both attached and planktonic groups.
Invasive Wetland and Aquatic Plant and Algal Species	Presence or absence, trends in abundance, distribution, density, and diversity.
Aquatic and Wetland Animal Community Structure and Composition	Trends in community diversity and richness over time.
Invasive Aquatic and Wetland Animal Species	Presence or absence, trends in abundance, density, distribution, and diversity.
Native Aquatic and Wetland Animal Populations	Trends in abundance of focal species size and age classes, distribution, and density.
Disease and Parasites in Aquatic Animals	Disease and parasite occurrence and frequency.
Wetland Hydrology	Plant cover, frequency and durations of inundation and saturation,, hydric soil characteristics, water circulation and residence time, pool size, depth & salinity, tidal fluctuations (coastal wetlands or anchialine pools), and pH.
Water Diversion Levels	Relative quantity of water being diverted or withdrawn. Includes seasonal, temporal, and spatial patterns.

LOCAL & PARK ISSUES

COLLABORATION WITH EXISTING EFFORTS

It is crucial for water quality-related monitoring within all parks to be coordinated with that being carried out by other agencies. Water issues do not stop at park boundaries and, in cases where urban development is upstream from park boundaries, land use will have a large effect on park resources. In addition, other agencies have established long-term monitoring protocols which it will be useful for the NPS to use as resources, such as the Environmental Protection Agency's EMAP Program.

KEY FRESHWATER RESOURCES

Freshwater and brackish resources vary widely among PACN parks. Management strategies for the organisms living within these different habitats will therefore differ from park to park. Descriptions of ecosystems and key groups of organisms may be found in the stream and wetland conceptual model sections.

Table Three summarizes freshwater resources in the PACN parks. Boundaries of ALKA have yet to be finalized, and USAR has no freshwater resources within its boundaries (though several streams drain into Pearl Harbor and border the park). Appendix A in this report is a table of named water bodies within the parks and the surrounding area of interest for water quality monitoring (see also the Water Quality report).

Table 3: Summary of freshwater resources of PACN parks.

	AMME	WAPA	NPSA	USAR	KALA	HALE	ALKA	PUHE	KAHO	PUHO	HAVO
Freshwater & Brackish Resources											
streams (perennial, intermittent, or ephemeral)	X	X	X	X	X	X	X	X		X	X
high elevation or non-coastal bogs, wetlands, and seeps		X	X		X	X					X
coastal wetlands or mangrove forest	X	X	X				X	X	X	X	
lakes					X	X					
anchialine pools					X		X	X	X	X	X
fishponds							X		X	X	
Biological Resources[1]											
threatened & endangered freshwater & brackish species and species of concern	X	?	?	?	X	X	X	?	X	?	X
amphidromous or catadromous species	?	?	X	?	X	X	X	?	?	?	?

1. Freshwater and brackish organisms have yet to be inventoried in several parks; see the Monitoring section for details.

KEY STRESSORS AND MANAGEMENT CONCERNS

Table Four summarizes the primary, immediate stressors and management concerns of freshwater resources in the PACN parks. These stressors and their effects on aquatic resources are discussed in detail in the conceptual models. Water quality issues are discussed in detail in the Water Quality Report (Appendix I).

Table 4: Summary of major, immediate stressors and natural resource management concerns of freshwater areas in PACN parks.

	AMME	WAPA	NPSA	USAR	KALA	HALE	ALKA	PUHE	KAHO	PUHO	HAVO
Invasive Freshwater or Brackish Species[1]											
invasive plants or algae	X	X	X	X	X	X	X	X	X	X	X
predatory aquatic animals	X	?	?	X	X	X	X	X	X	X	X
feral ungulates (contributing significantly to erosion)		X	X		X	X	X				X
terrestrial predators identified as threats to aquatic animals, disease, etc.	X	X	X	X	X	X	X	X	X	X	X
Adjacent Human Use											
land use	X	X	X	X	X	X	X	X	X	X	X
stream channelization (incl. outside park boundaries)	X	X	X	X	X		X				
surface water diversion	X	X	?	X	X	?	X				
groundwater withdrawal	X	X	X	X	X		X	X	X	X	
water quality (nutrients, pollutants, sedimentation, etc.; see also Water Quality report)	X	X	X	X	X	X	X	X	X	X	X
In-Park Use											
visitor damage (including litter & dumping)	X	X	X		X	X	X	X	X	X	X
subsistence agriculture (incl. use of wetlands)			X			X					
aquatic hunting & gathering					X		X		X		
terrestrial hunting & gathering	X	X	X		X	X	X				X
Natural Hazards											
volcanic activity (both current & likely)	X	X				X	X	X	X	X	X
frequent tropical cyclones	X	X									

1. Freshwater and brackish organisms have yet to be inventoried in several parks; see the Monitoring section for details.

PARK FRESHWATER RESOURCES AND STRESSORS

Freshwater ecosystems, key biological resources, and stressors of freshwater systems are tabulated for each park in Tables 5-15. These tables include details about habitat types, rare, threatened, and endangered species within the parks, and details about current or predicted stressors and management concerns.

Table 5: Freshwater habitats, critical biological resources, and stressors of AMME.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	One stream borders the park; it is highly degraded and has not been inventoried.	Federally endangered species: Mariana gray swiftlet (*Aerodramus vankorensis bartschi*), Nightingale reed-warbler (*Acrocephalus luscinia*), Mariana moorhen (*Gallinula chloropus guami*). Commonwealth endangered species: Micronesian Gecko (*Perochirus atales*). Candidate endangered species: *Partula gibba* (tree snail). The wetland is one of the last remaining wetlands on Saipan, and is unique within the CNMI.	**Land use**	Part of the coastal wetland has been filled, and was previously used as a dump; a nearby dump is still in use. Illegal dumping still occurs, and there is concern about contaminants from previous dumping (PCB's were cleaned from the dump in the past) and trash blowing into the park.
Wetland	A coastal mangrove swamp and non-saline inland wetland. These were originally a single wetland complex, but have been separated by road construction.		**Water supply (see Water Quality report for more details)**	The stream bordering the park drains the town of Garapan, and water is affected by urban pollutants. A desalinization plant also releases highly saline, warm effluent into the stream. Flash flooding occasionally occurs, and urban development surrounds the park, leading to contaminated surface runoff during rains.
Anchialine pool	No.		**Invasive species**	Shrews (*S. marinus)* have been documented in the park, and there have been undocumented sightings of the Brown tree snake (*B. irregularis)*. Invasive vines, scarlet gourd (*Coccinia grandis*) and chain-of-love (*Antigonon leptopus*), are found on the edge of the wetland, and introduced mosquitofish (*Gambusia affinis*) and tilapia (*Sarotheradon mossambicus*) are present.
Other	No.		**Direct resource use**	None known.

Table 6: Freshwater habitats, critical biological resources, and stressors of WAPA.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	A number of perennial and intermittent streams are located within or border various park units. These streams may contain native gobies and other fauna.	Proposed critical habitat of the Micronesian kingfisher (*Halcyon cinnamomina*) may extend into the Mt. Alifan unit of the park. The Mariana fruit bat (*Pteropus marianus marianus)* may be present in forested regions, as well as native tree snails. The wetlands have not been inventoried.	**Land use**	Intermittent streams carry heavy sediment loads during rain. The U.S. military operates upland from the coastal Asan & Agat units, possibly contributing to sedimentation and chemical pollution. Frequent upslope wildfires contribute to the erosion problem. The Asan unit is located next to a dump. Development has contributed to the filling of many wetlands adjacent to the park.
Wetland	There are several coastal wetlands areas on or near park boundaries and small forested wetlands and bogs in inland park units.		**Water supply (see Water Quality report for more details)**	Sediment loads and probable high levels of pollutants affect intermittent streams. Water supply on Guam is limited, which may result in reduced groundwater recharge to the wetlands.
Anchialine pool	No.		**Invasive species**	The Brown tree snake (*B. irregularis)* and shrew (*S. marinus)* are the primary threat to native animals. Several invasive plants have become established within the park. The presence of other aquatic invasive species is probable, but not documented.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Other	Springs.		**Direct resource use**	Hunting is permitted within park units.

Table 7: Freshwater habitats, critical biological resources, and stressors of NPSA.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	About 20 perennial or intermittent streams or parts of streams are located on Tutuila, 10 on Ofu & Olosega, and 1 stream on Tau.	Streams within the park have not been inventoried recently (with the exception of Laufuti Stream on Tau), but contain native species of fish, macroinvertebrates, and insects. Wetlands likely are utilized by rare birds and invertebrates.	**Land use**	Issues in streams include sedimentation from land clearing and erosion and damage from feral pigs (*S. scrofa)*. In a few streams, villages occur on lower reaches of streams (which are outside the park boundary), affecting amphidromous & catadromous fauna. Wetlands are often used for agriculture, particularly taro (*C. esculenta*) cultivation.
Wetland	Possible isolated high-elevation and small coastal wetlands. A mangrove wetland and marsh in Vatia is adjacent to the park boundary.		**Water supply (see Water Quality report for more details)**	Water supply is affected by pollution from piggeries and a nearby village dump, septic tanks and sewage. There is the possibility of organic pollution from aquaculture.
Anchialine pool	No.		**Invasive species**	Several species of invasive fish have been detected in streams on Tutuila. There is the possibility of alien species being released from aquaculture.
Other	Possibly seeps, springs, and waterholes.		**Direct resource use**	Fishing and hunting are permitted within the park.

Table 8: Freshwater habitats, critical biological resources, and stressors of USAR.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	Several highly degraded urbanized streams drain into Pearl Harbor.	No freshwater biological resources are located within the park.	**Land use**	This park's main resource is the submerged ship. The visitor's center is built on fill, and the Pearl Harbor watersheds are highly urbanized.
Wetland	Estuarine wetlands are located near park boundaries.		**Water supply (see Water Quality report for more details)**	Streams entering the harbor pass through urban, agricultural, and industrial areas, so are affected by various pollutants.
Anchialine pool	No.		**Invasive species**	No freshwater resources are located within the park; nearby freshwater resources are affected by multiple invasive species.
Other	No.		**Direct resource use**	No freshwater resources are located within the park.

Table 9: Freshwater habitats, critical biological resources, and stressors of KALA.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	Several streams are located within the park boundary.	Candidate endangered species: two species of damselfly (*Megalagrion pacificum* and *M. xanthomelas*). Two diving expeditions have entered the lake, and found that the lake has unique characteristics. It was designated a Special Ecological Area in 1994. A new species of copepod and a genetically isolated population of shrimp (probably *Palaeomon debilis*) were found in the lake in 1999. Native fish and invertebrates are found within and around the streams.	**Land use**	Access to this park is restricted, and land use is largely limited to the settlement. Lands above the park are used for agriculture. A former dump is located within the park. Pelekunu Stream (near the border of KALA) has been included in the Nature Conservancy's national list of "Priority Aquatic Sites for Biodiversity Conservation" and is part of the Molokai Cliffs National Natural Landmark. Waikolu, Wainene, Anapuhi, and Waioho`okalo Streams are all part of the state Pu`u Ali`i Natural Area Reserve System. Wainene, Anapuhi, Waioho`okalo, Keawanui, Ka`ili`ili, and Pelekunu Streams all are associated with the Nature Conservancy's Pelekunu Preserve (HCPSU 1990).
Wetland	No.		**Water supply (see Water Quality report for more details)**	Several stressors affect streams, including erosion caused by feral pigs (*S. scrofa)* and significant water diversion for agriculture, as well as for drinking water on the peninsula.
Anchialine pool	No.		**Invasive species**	The Tahitian prawn (*M. lar*) is established in Waikolu Stream, and is likely present in the others. Alien species have the potential to significantly impact unique aquatic biota in Lake Kauhako , though none are known from there.
Other	A lake located within Kauhako Crater is the fourth-deepest in the U.S. and has the highest ratio of depth to surface area of any lake worldwide; it is anchialine. An inland manmade fishpond is located near Iliopihi Bay (Wyban 1993). It is in disrepair and may now be considered an anchialine pool. There are likely several seeps and springs within the park.		**Direct resource use**	Shrimp (*Atyoida bisculcata*) and hihiwai (*N. granosa*) collecting occurs in the streams.

Table 10: Freshwater habitats, critical biological resources, and stressors of HALE.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	Several streams are located within the park.	Several streams have populations of native fish and invertebrates. The high-elevation bogs support rare plants and insects (including *Megalagrion* spp.). Lake Wai`ele`ele has been inventoried for invertebrate & plant species; the three lakes are not known to contain fish.	**Land use**	Water resources on former State lands within the park are reserved for uses outside the park, though they have not been diverted for such purposes at this time. Grazing along streams in Kipahulu may contribute to erosion and elevated nutrient levels (A. Brasher, pers. comm.). Palikea and Pipiwai Streams (`Ohe`o Gulch) and Koukouai Stream have been identified as being eligible for designation as national Wild and Scenic Rivers. Pua`alu`u Stream (on the border of HALE) has been included in the Nature Conservancy's national list of "Priority Aquatic Sites for Biodiversity Conservation". Park contains waterfalls listed in the Hawaii Stream Assessment's "Hawaii's Waterfalls" list (HCPSU 1990).
Wetland	High-elevation bogs.		**Water supply (see Water Quality report for more details)**	No significant concerns, other than visitor use. Erosion caused by feral ungulates may be a problem in unfenced areas.
Anchialine pool	No.		**Invasive species**	The alien Tahitian prawn (*M. lar*) is present in the `Oheo Gulch and Pua`alu`u Stream, and is likely present in streams in the Ka'apahu section. In the mid-1990's, an infestation of introduced leeches was observed on fishes in the lower `Ohe`o Gulch pools (A. Brasher, pers. comm.).
Other	Three high-elevation lakes. Several springs are present in other areas. High-elevation lakes are extremely rare in the Hawaiian Islands, and these represent an important resource. High elevation areas are restricted-access, as is the high elevation part of Kipahulu valley.		**Direct resource use**	Human activity is increasing at streams in the Kipahulu section, and a septic tank is currently being installed near the mouth. Flash flooding in this stream has caused several visitor deaths. Kalo (*C. esculenta*) farming is practiced in Ka`apahu Stream, and animals are grazed near streams in Kipahulu Valley.

Table 11: Freshwater habitats, critical biological resources, and stressors of ALKA (park boundaries have yet to be established).

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	Expected to include several intermittent and interrupted streams.	Federally-listed endangered or threatened freshwater or wetland species which may be found within the ALKA boundaries were listed in the Trail Study/EIS. These included 3 waterbirds, 7 anchialine shrimp, and 1 snail. The Hawaii Natural Heritage Program provided a list of imperiled species including those listed above plus 2 shrimp, 1 bird and 1 eel (HNHP 1987).	**Land use**	Stressors in this park include those affecting PUHE, KAHO, PUHO, and HAVO. In addition, this park includes urbanized areas, which may be experiencing different stressors. Park boundaries and a comprehensive management plan have not been established.
Wetland	Resources in this park are expected to include springs and seeps, fishponds, and coastal wetlands.		**Water supply (see Water Quality report for more details)**	Portions of the trail pass downslope from or through urban and industrial areas; water quality from both surface water and groundwater contamination is a concern in these areas.
Anchialine pool	The route for the ALKA passes through the Kona coast, which contains ~70% of the state's anchialine pools.		**Invasive species**	Invasive fish, vertebrates, plants, and amphibians are present in most wetlands and anchialine pools. Pools are commonly stocked with predatory invasive fish species for use as bait.
Other	The management plan for this park is currently being written. It is located along a large distance of the coast of Hawaii Island. Resources and resource types will include coastal resources of PUHE, KAHO, PUHO, and HAVO		**Direct resource use**	*Halocaridina rubra* (anchialine shrimp), a species of concern, is likely being gathered as part of the aquarium trade. Visitors may also bathe in pools, causing physical damage and pollution. Lack of public toilets in many popular areas is an increasing problem.

Table 12: Freshwater habitats, critical biological resources, and stressors of PUHE.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	One intermittent stream, which may have been perennial in the past (based on anecdotal evidence).	Native invertebrates, fish, and plants may be found in the stream and wetland. This area has not been inventoried.	**Land use**	Dirt biking around the stream and marsh is causing erosion. Illegal dumping in the streambed near the highway creates a solid waste problem. A former concrete plant upstream has cemented the channel in one place. Harbor construction has significantly altered coastal habitat; the estuarine wetland was created when the stream was rerouted.
Wetland	A former Hawaiian fishpond located at the stream mouth is now an estuarine wetland; plans exist to restore the marsh's connection to the sea.		**Water supply (see Water Quality report for more details)**	There are water quality issues due to the proximity of Kawaihae Harbor. There is also concern that upslope groundwater withdrawal has contributed to a loss in wetland area.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Anchialine pool	No.		**Invasive species**	Much of the riparian and wetland vegetation is alien.
Other	No.		**Direct resource use**	None known.

Table 13: Freshwater habitats, critical biological resources, and stressors of KAHO.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	No.	Endangered species: Hawaiian Stilt (*H. mexicanus knudseni*) and Hawaiian Coot (*F. alai*). Candidate endangered species: Orangeblack damselfly (*Megalagrion xanthomelas*) and *Metabetaeus lohena* (anchialine shrimp). Species of concern: *H. rubra* (anchialine shrimp). Rare species: *Neritilia hawaiiensis* (anchialine snail).	**Land use**	The primary concern is recent change in zoning of the lands surrounding the park from conservation to urban/ industrial. There is a current Contested Case hearing on the application for a permit to expand the upslope industrial park. Proposals for a resort/ luxury housing development on the north side of the park and harbor expansion on the south side of the park are also concerns.
Wetland	A fairly extensive wetland area is located adjacent to \`Aimakapa fishpond, and a smaller one near Kaloko Pond.		**Water supply (see Water Quality report for more details)**	There is concern that Industrial Park development has led to increased levels of groundwater pollutants and nutrients, which would affect the coastal resources. Population increase will likely also lead to increased groundwater pumping for human consumption, reducing the freshwater recharge to anchialine pools.
Anchialine pool	Several dozen anchialine pools.		**Invasive species**	Alien species are a large concern. Large fish in \`Aimakapa pond may prey upon the chicks of endangered waterbirds; fish may be added by fishermen. Invasive plants such as Red mangrove (*R. mangle*) and pickleweed (*B. maritima*) present a threat to resources. Most anchialine pools contain invasive predatory topminnows.
Other	The large man-made Kaloko and \`Aimakapa fishponds. Kaloko is a brackish pond which is being restored as a traditional working fishpond, while the lower-salinity \`Aimakapa is being managed as waterbird habitat.		**Direct resource use**	Anchialine shrimp (*H. rubra*), which are a species of concern, may be taken as part of the aquarium trade. Visitors also bathe in the pools, causing physical damage and pollution. Fishing occurs in Kaloko Pond, which is being restored to a working traditional fishpond.

Table 14: Freshwater habitats, critical biological resources, and stressors of PUHO.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	An intermittent stream (Ki`ilae).	One brackish inland fishpond was used during historic times, so may be regarded as both a cultural and natural resource for restoration purposes. Native invertebrates are found in one anchialine pool, but the others are degraded and restoration is necessary.	**Land use**	One pool and a sinkhole are located near park vegetation dump sites, and the larger pools and fishponds are located in high visitor use areas.
Wetland	Anchialine pool-associated marsh.		**Water supply (see Water Quality report for more details)**	The primary concern in this park is upslope development and its associated degradation of groundwater quality, as well as increased pumping of groundwater. Alien plant control methods within the park may lead to pollution of pool water and sediments with herbicides.
Anchialine pool	Several anchialine pools.		**Invasive species**	Both invasive terrestrial plants and aquatic animals are present; the introduced fish tilapia (*Oreochromis* spp.) is a voracious predator with as wide range of salinity tolerance and has become established as a dominant species in several pools.
Other	Seeps and waterholes, also a man-made fishpond.		**Direct resource use**	Anchialine shrimp may be taken for the aquarium trade. There is interest in restoring the fishpond to a working cultural pond.

Table 15: Freshwater habitats, critical biological resources, and stressors of HAVO.

Habitat type	Habitat details	Critical biological resources	Stressor type	Stressor details
Stream	Several ephemeral streams exist in the Ka`u region.	Native fish and invertebrates are found in anchialine pools, possibly including threatened or endangered species. A species of blind eel (*Anguilla* sp.) has recently been re-discovered in anchialine pools.	**Land use**	Volcanic activity forms a hazard to anchialine pools in this park. A cave/pool complex at Waha`ula was covered by lava in 1989.
Wetland	The `Ola`a tract contains several boggy areas, as does the Kipuka Nene area of Kahuku Ranch.		**Water supply (see Water Quality report for more details)**	No significant concerns, other than visitor use.
Anchialine pool	Primary freshwater resources in this park are anchialine pools.		**Invasive species**	Invasive species include the Tahitian prawn (*M. lar*), which preys upon and displaces the native prawn and shrimp species, and the riparian sourbush (*Pluchea odorata)*, which deposits significant amounts of dead matter in the pools, filling them.
Other	The recent acquisition of Kahuku Ranch has added substantial acreage, which is expected to contain seeps, springs, and intermittent streams. A pool is found on the floor of Halemaumau Caldera.		**Direct resource use**	High visitation threatens the anchialine pools: bathing by visitors in pools may affect aquatic life.

MONITORING

ESTABLISHED MONITORING PROGRAMS IN THE PACN REGION

Many aquatic monitoring programs in the PACN region focus on physical and chemical measures of water quality, rather than biological or habitat quality measures. Such programs are reviewed in the Water Quality workgroup report. This section lists only those programs that contain a biological or habitat quality component. Information on established monitoring programs and copies of protocols will be gathered as part of the vital sign selection and protocol development process.

Federal programs

Several federal agencies have biology-related water monitoring. These include: the U.S. Geological Survey (both NAWQA and the Water Resources Division), the Environmental Protection Agency (Environmental Mapping and Assessment Program, or EMAP), the U.S. Fish and Wildlife Service, and the Natural Resources Conservation Service.

Other programs

Several state and territorial agencies use federal protocols to monitor aquatic resources. Community groups and non-governmental organizations are also involved in monitoring projects. Governmental agencies conducting monitoring include: the Hawaii Division of Aquatic Resources, Hawaii Stream Research Center, Hawaii Department of Health, American Samoa EPA, Guam EPA, and CNMI Department of Lands and Natural Resources. Universities involved with monitoring projects in various parks include the University of Hawaii and University of Guam. Non-governmental organizations with monitoring programs in the region include the World Wildlife Fund, the Nature Conservancy, and Ducks Unlimited.

PAST PARK INVENTORIES AND MONITORING

This section includes information on past park inventory, research, and monitoring programs which had an emphasis on freshwater biology. Water quality-related activities are summarized in the Water Quality workgroup report.

AMME

Best (1981) complied a bibliography of published reports and journal articles relating to freshwater resources in the Marianas Islands, including Saipan. A general vegetation survey of the park was completed in 1989 (Raulerson & Reinhart). A more recent survey of wetland plants and vegetation mapping has been completed, but NPS is waiting for a final report (as of Aug. 2004). A census of terrestrial Nightingale reed-warbler (*Acrocephalus luscinia*) predators was supposed to be conducted to accompany the vegetation survey, but it is not clear whether this has been completed (as of Sept. 2004). The government of the CMNI currently conducts coastal water quality monitoring.

Monitoring and management needs

The results of the inventory of wetlands biology need to be completed and integrated into a management plan. A biological inventory should be conducted in the stream, and results integrated into a water quality monitoring and management plan. There are no dedicated natural resource personnel at this park, but personnel may be shared with WAPA. The mangrove swamp and wetland is the most significant terrestrial habitat in the park; its hydrology is incompletely understood at this time and should be studied. USGS hydrological research on the wetland-ocean connections is ongoing (as of Sept. 2004). The scope of work for future planned mangrove swamp monitoring is currently being written; it will likely include monitoring plant and animal species as well as pollen coring to determine past plant species distributions. Monitoring for and response to invasive species such as the Brown tree snake (*B. irregularis*) and known invasive plant species is crucial for the maintenance of this unique ecosystem.

WAPA

Best and Davidson (1981) compiled information on location, physical parameters, and some components of Guam streams, springs, and wetlands. Best (1981) complied a bibliography of published reports and journal articles relating to freshwater resources in the Marianas Islands, including Guam. The USGS has conducted (March 2004) a baseline survey of streams within the park which collected observations on biology, stream morphology, erosion patterns, flow rates, and locations of human modifications. A report is forthcoming. Prior to this, no stream assessments had been conducted since 1963. A botanical inventory has recently been conducted (July 2004) as part of the Inventory and Monitoring program; this inventory included wetland areas. A report is forthcoming.

Monitoring and management needs

The Guam EPA is developing a "Freshwater Periphyton and Benthic Macroinvertebrates Assessment Program" for water quality monitoring in streams; this program should be applied in park streams. Erosion is a problem in the coastal units. Restoring riparian areas will lessen this problem somewhat; a restoration project of this sort would likely be cooperative. An inventory of stream biology and habitat quality should be carried out, including aquatic insects, plants, and algae. Wetland and high-elevation boggy areas should be delineated, mapped, and biotic inventories should be conducted. Once Micronesian kingfisher (*H. cinnamomina*) critical habitat is designated, it should be noted whether any park lands lie within this area. In aquatic habitats (including wetlands), invasive species management should be carried out to preserve remaining native species.

NPSA

The U.S. Army Corps of engineers surveyed both macrofauna (fish, mollusks, and crustaceans) and physical stream parameters (morphology, hydrology, and water chemistry) in several streams on Tutuila as part of a stream inventory (ACOE 1981). A map inventory of all American Samoa streams, springs, and wetlands was also begun but not completed (Burger & Maciolek 1981). An inventory of aquatic macroinvertebrates and fish has recently been conducted in Laufuti Stream, on Tau (Cook 2004). A stream bioassessment is in the process of being planned on Tutuila, as is a study of stream water quality (as of Aug. 2004). Coastal marsh and mangrove forest in Vatia village (adjacent to the park) were mapped in 1976 (Whistler) and 1992 (BioSystems Analysis).

Monitoring and management needs

Once the Tutuila stream biotic inventory is completed, results should be integrated into a management plan. The Ofu and Olosega streams should be inventoried; even if these streams are not perennially flowing they may have perennial aquatic plant and insect habitat in pools. Monitoring of water quality should be undertaken, especially downstream from areas of human activity; this type of monitoring would likely be integrated with a coral reef water quality monitoring plan. Attention should be paid to aquatic biology, especially amphidromous or catadromous species and rare species which could serve as biological indicators. A biological inventory and mapping of the Vatia mangrove swamp and marsh should also be undertaken. Other aquatic habitats within the park, such as springs, seeps, waterholes, and mid-elevation and coastal wetlands, should be inventoried and mapped.

USAR

No freshwater resources are located within park boundaries, though several highly modified streams drain into the Pearl Harbor watershed. The Oahu National Water Quality Assessment Program (NAWQA) unit has sampled stream organisms in urban Honolulu (Brasher & Anthony 2000, Oki & Brasher 2003, Anthony et al. 2004).

Monitoring and management needs

As part of an invasive species monitoring program, the Pearl Harbor area should be monitored for aquatic invasive species, including estuarine and freshwater organisms. The marine larval stages of native amphidromous and catadromous species may also be present in the harbor waters, however, significant restoration efforts would likely be required for the streams in the East Loch watersheds to provide satisfactory adult habitat.

KALA

Several ecological studies have been conducted on macrofauna (fish, snails, and shrimp) in Waikolu and Pelekunu Streams (Brasher 1996, 1997a, 1997b). Macrofauna in other streams have not been inventoried. Surveys of aquatic insects have also been conducted (Polhemus 1992). Monitoring protocols for hihiwai (*Neritina granosa*) in streams have been established. Aquatic fauna of Lake Kauhako was inventoried in 1999, though it is unknown how many species are present or how many new species may be discovered. Water quality and bacterial sampling has also been done in Lake Kauhako. As part of the anchialine pool invertebrate inventory being conducted by D. Foote in 2003-2004, Lake Kauhako is scheduled to be inventoried.

Monitoring and management needs

Park needs include baseline inventories for stream macrofauna, aquatic insects, plants, and algae in all streams, including Waikolu Stream. Water quality and biotic monitoring of Lake Kauhako should continue, with emphasis on locating unique invertebrates. The fishpond should be evaluated for possible restoration or management for damselfly or waterbird habitat. A monitoring program of aquatic macrofauna, including hihiwai (*N. granosa*), should be initiated in perennial streams. Water withdrawal and feral pig (*S. scrofa)* activity is a significant concern for stream fauna, and the effects of these stressors should be monitored. Seeps and springs should be located and inventoried.

HALE

Stream macrofauna inventories have been conducted in the past (Hodges 1994, Kinzie & Ford 1977, 1979) in Palikea, Pipiwai and Pua`alu`u Streams. Surveys of insects and riparian vegetation have also been conducted (Hardy 1979, Polhemus 1993). Streams in the Ka’apahu section have not been extensively inventoried, except for a partial macrofauna inventory for lower Alelele Stream. Insect and aquatic fauna in one high-elevation lake (Wai`ele`ele) have been inventoried, as well as bog vegetation (Loope et al. 1991a, 1991b, Medeiros et al. 1991).

Monitoring and management needs

A botanical and zoological inventory of all streams in the recently-acquired Ka`apahu section should be conducted. Biotic inventories need to be conducted in the upper reaches of all streams, including those in the Kipahulu Study Area. Basic water quality information and biological inventories are needed for all 3 high-elevation ponds. Information is also needed on the insect fauna of the bogs. Biological monitoring of streams should be implemented as part of any water quality monitoring program. Seeps and springs should be located and inventoried.

ALKA

Several inventories of coastal habitats, including anchialine pools, have been conducted by various groups (e.g., Maciolek & Brock 1974, Maciolek 1987), noting such information as pool locations, fauna & flora present, and physical and chemical parameters. At present, it is uncertain what freshwater resources will be located within park boundaries. Anchialine pool management programs are currently in place at several of the resorts along the trail, including the Four Seasons Hualalai Resort (North Kona), and Waikoloa and Mauna Lani Resorts (Kohala). `Opae`ula Pond, in North Kona, is being restored as waterbird habitat by USFWS, NRCS, Kamehameha Schools/Bishop Estate, and Ducks Unlimited. The State Kipahoehoe and Manuka Natural Area Reserves in South Kona include anchialine pools.

Monitoring and management needs

When park boundaries and jurisdiction are finalized, basic mapping surveys and biological inventories of freshwater resources and associated biota will be needed. The proposed route of this trail passes through or near some of the most significant wetlands and anchialine pool complexes on the island. Once trail boundaries are finalized, long-term monitoring and management will be necessary in areas such as anchialine pools and wetlands, especially those which receive high human visitation. Monitoring and management will be dependant on partnerships and cooperation between the park and landowners and community groups.

PUHE

Water quality and aquatic species inventories of the anchialine estuarine wetland have not been completed, although a partially-completed survey exists. As part of the anchialine pool invertebrate inventory being conducted by D. Foote (USGS) in 2003-2004, the estuarine wetland/ anchialine pool is scheduled to be surveyed. The Mauna Kea Soil and Water Conservation District conducts limited water-quality and stream flow monitoring in the stream.

Monitoring and management needs

A thorough inventory of biology in both the wetland and the estuarine/ anchialine pool needs to be conducted. The sandbar at the mouth of the stream seasonally washes out, creating a more open connection to the ocean, and affecting salinity and water circulation in the wetland. The park should monitor the aquatic biota to characterize community dynamics during this annual event.

KAHO

Several inventories of biology (fauna & some flora) and water quality have been conducted in anchialine pools and fishponds (Maciolek & Brock 1974, Maciolek 1987). More comprehensive surveys were conducted in anchialine pools and Kaloko fishpond recently (Brock & Kam 1997, Brasher 1999). Many smaller anchialine pools are only visible at high tide. As part of the anchialine pool invertebrate inventory being conducted by D. Foote (USGS) in 2003-2004, several anchialine pools are scheduled to be inventoried. Fish species in Kaloko Fishpond have been surveyed at least twice (see Brasher 1999). Studies of waterbird breeding behavior and progress of botulism outbreaks have been conducted (Morin 1996, 1998).

Monitoring and management needs

Anchialine pools need to be inventoried for species of concern which are expected to be present (damselflies, aquatic flies, shrimp (*Palaeomonella burnsii* and possibly other species) and a snail (*Neritilia hawaiiensis*). An inventory of fish in `Aimakapa Pond should be undertaken, and a study on the possible role of large fish in fledgling waterbird mortality should be conducted. Kaloko fishpond wall and *makaha* restoration are currently being undertaken, and the effects on aquatic life should be monitored. Plans for `Aimakapa Pond are to manage it as waterbird habitat. Park management also wishes to remove alien fish from anchialine pools. Anchialine pools need to be consistently GIS-mapped and marked.

PUHO

A study by a community school group in 1992 examined water quality, biology, and mapping of the 2 anchialine fishponds, and short species checklists were developed (Oceanic Institute 1992). A water quality inventory of springs, waterholes, anchialine pools, and nearshore marine waters was begun in 2002. Vegetation monitoring was begun in 1986, including mapping vegetation in the wetland. As part of the anchialine pool invertebrate inventory being conducted by D. Foote (USGS) in 2003-2004, the fishponds and other anchialine pools are scheduled to be surveyed.

Monitoring and management needs

Water quality and aquatic biology inventories should be completed for all anchialine pools, seeps, wells, fishponds, and the wetland. Pools, seeps, and other freshwater features should also be accurately GIS-mapped and marked. Management needs are alien species removal, native plant propagation, and sediment removal in certain pools.

HAVO

An inventory of 19 anchialine pools was conducted in 1989 by Chai and colleagues, although other pools are known to exist. One of the pool complexes (Waha`ula Wet Cave) has since been covered by lava. As part of the anchialine pool invertebrate inventory being conducted by D. Foote (USGS) in 2003-2004, several anchialine pool complexes are scheduled to be surveyed. Since 2003, D. Foote has been monitoring pool-breeding damselflies and flies, as well as habitat, in the mid-elevation `Ola`a Pu`u unit.

Monitoring and management needs

Zoological and botanical inventories should be conducted in all anchialine pools, both those visited by Chai and colleagues in 1989 and those not previously surveyed. Alien riparian vegetation should be cleared and possibly waste removed from pools. Pools should be GIS-mapped and marked. Ephemeral stream habitat in Ka`u should be surveyed for native insects. Springs, seeps, and other freshwater habitats are present on the `Ola`a tract, and are likely to be present within the Kahuku addition. Invertebrate fauna and plants should be inventoried and monitored where possible in these areas.

General Research Needs

In addition to the research questions outlined in the conceptual models, several research areas of interest have been identified for the Pacific Islands Network.

Anchialine Pools

Research is needed on the ecology of anchialine pools and on the impacts of upslope development on groundwater quality as it affects these resources, as well as other coastal wetlands. Surveys of the algal and aquatic plant species are also needed. The ecology of these systems is not entirely understood, and they are a critically imperiled resource in the nation due to coastal development. (Parks: KAHO, PUHO, HAVO, ALKA)

Amphidromous and Catadromous Species

Several amphidromous and catadromous species live within the parks. Populations breeding within National Park streams could serve as source populations to streams islandwide, and research on their ecology and life history is important to understand their needs for food and habitat. (Parks: NPSA, KALA, HALE, possibly AMME, WAPA, USAR, PUHE)

Biotic Indices of Water Quality

In areas where sufficient baseline data exists, benthic algae or invertebrates are often used as indicators of trends in water quality. Some work on the relationship between organisms and water quality has been done in the PACN region (e.g., Zolan 1981, Anthony et al. 2004, Stephens 2003), but more research is necessary. (Parks: All)

Research Questions Identified in Conceptual Models

a. Relationship of aquatic animal community to available food sources

Studies in Hawaii suggest that several native stream fish are opportunistic feeders that will utilize algae and both native and alien insects. What is the effect of changes in food availability on native aquatic animal communities in other island groups? Do feeding preferences of aquatic animals significantly affect the structure of aquatic primary producer communities?

b. Effect of parasites and disease on native stream animals

Many fish parasites in Hawaiian streams have been shown to be introduced. To what degree do parasites and disease affect native fish in the rest of the PACN? Are parasites and diseases native, or were they introduced along with alien species? Is there a relationship between alien fish density and parasite loads? What are the levels of disease and parasitism on aquatic invertebrates?

c. Relationship of riparian plant communities to instream and lake processes

Riparian plant communities in the PACN are often highly modified. Where riparian plant communities do exist, what effects does the replacement of native plant species with alien species have on nutrient cycling, shade patterns, organic matter input, and subsurface water flow into the water body? In turn, how do these processes affect patterns of primary and secondary productivity?

d. Relationship of aquatic primary producer and consumer communities to water quality

Which nutrients most limit aquatic primary productivity in PACN streams, lakes, and wetlands? What effect do specific contaminants have on primary producers and consumers?

e. Effect of invasive plant and animal species on wetland communities

Wetlands in the PACN (including anchialine pools, marshes and swamps) are known to be affected by multiple invasive species of plants and animals. While anecdotal information exists about these effects, very little quantitative research exists on Pacific islands. What are the effects of competitive interactions between native and alien species on the biotic community as a whole? How are patterns of nutrient cycling influenced by the establishment of invasive plant species? Which alien species, once established, fundamentally alter wetland ecosystems?

f. Native keystone species

Which native species, once extirpated, fundamentally alter wetland ecosystems? It has been hypothesized that the most common species of anchialine shrimp (*H. rubra*) acts as a keystone species in anchialine pool ecosystems. *H. rubra* removal (due to predation by introduced alien fish) is correlated with overgrowth of mat-forming algae by longer filamentous algae (Bailey-Brock & Brock 1993, Brock & Kam 1997), but rigorous testing of this hypothesis should be done. Do other, less common, anchialine pool shrimp species play a similar role?

g. Effect of sea level rise on coastal wetland hydrology

While the general effects of sea level rise on coastal wetlands are predictable (i.e., increased saltwater intrusion and wave action), site-specific effects are not. Which PACN wetlands are most at risk from sea level rise? What are possible mitigation strategies that will allow the preservation of species that live in these ecosystems?

h. Effect of climate change on the trade-wind inversion level

Increases in sea surface and air temperatures are predicted to occur as a result of global climate change. What will the effect of these changes be on the trade-wind inversion and cloud lifting levels? What will the effects of a shift in trade-wind inversion level be on the present high-elevation bogs and lakes?

i. Groundwater dynamics

While older Pacific islands have groundwater hydrology which is largely understood, younger islands have less-predictable groundwater dynamics. Groundwater withdrawal is increasing on

Pacific islands for human consumption, especially as populations continue to grow. How does young volcanic geology affect movement of groundwater? How do groundwater dynamics affect movement of pollutants through groundwater and into aquatic systems? How will groundwater withdrawals affect wetland hydrology? What is the relationship between groundwater withdrawal and base flow of streams?

CONCLUSIONS

Freshwater ecosystems are often limited in spatial distribution, but are critical considerations for natural resource issues in all parks. Despite small land areas, several different freshwater habitat types are present in the Pacific Island Network (PACN), some of which are unique within the United States. The Freshwater Biology topical workgroup has been constructed to gather information about all inland water bodies, fresh or brackish, including anchialine pools, manmade fishponds, streams, wetlands, bogs and similar areas. Habitats such as anchialine pool systems are rare worldwide, and only are present in Hawaii in the United States. Freshwater ecosystems are internationally considered to be among the world’s most vulnerable (UNEP 2004) Organisms which use these ecosystems include algae, other microorganisms, vascular and nonvascular plants, vertebrates, and invertebrates.

The diverse freshwater and brackish ecosystems within the PACN contain a wide array of biological resources, for which several areas of concern for management have been identified. The NPS is one of the few agencies within the Pacific Island region with jurisdiction over these resources and a mandate to protect them in an unimpaired state. Well-informed management is important for maintenance of their ecological integrity, which is crucial so that these species and ecosystems are not destroyed.

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APPENDIX A- LIST OF NON-MARINE AQUATIC RESOURCES ASSOCIATED WITH PACN PARKS.

This list includes resources within authorized park boundaries, as well as those within the designated water quality area of interest which affect park resources (i.e., streams that drain into park embayments) or which share unique hydrological and biological features (e.g., anchialine pool complexes and montane bogs). See http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/waterq.htm for maps of the designated water quality area of interest for each park. This list includes most of the named waterbodies, but not many smaller resources like seeps and springs. It also does not include water bodies within the Kahuku addition to HAVO or those along the ALKA trail corridor not within another established park.

Park	Name	Type	Location	Within park	Notes
WAPA	Maina	Spring	Fonte Plateau Unit	possibly	
	Asan	River	Asan Unit	mouth & part of body	has 2 tributaries, partially channelized, usgs gauge
	Asan	Spring	Asan Unit	yes	
	Matgue	River	Asan Unit	mouth & part of body	has 1 tributary
	Taguag	River	Piti Unit	part of body	no tributaries
	Masso	River	Piti Unit	possibly part of body	has intermittent tributaries, reservoir above park
	Namo	River	Agat Unit	mouth	has 2 perennial tributaries, partially channelized, also referred to as Ayuga drainage area, gauged, wetland near mouth
	Namo	Wetland	Agat Unit	yes	coastal wetland, listed in United Nations Environment Program's list of protected wetlands
	Togcha	River	Agat/Mt. Alifan Unit	mouth & headwaters	no tributaries
	Salinas	River	Agat/Mt. Alifan Unit	mouth & headwaters	no tributaries, bisects town of Agat
	Finile	Creek	Agat/ Mt. Alifan Unit	mouth & possibly headwaters	fed by 3 springs, 2 perennial tributaries, gauged, part of Agat flood basin w. Chaligan, Auau & Gaan Streams
	Finile & Faata	Spring	Mt. Alifan Unit	possibly	
	Gaan	River	Agat/ Mt. Alifan Unit	mouth & possibly headwaters	part of Agat flood basin
	Auau	Stream	Agat Unit	mouth	part of Agat flood basin
	Ylig	River	Mt. Chachao/Mt. Tenjo Unit	possibly headwaters	2 major tributaries, supplies Yona Village w. drinking water
	several	Wetlands	mid-elevation areas	yes	several unnamed perched wetlands
AMME	?	Stream	within park	yes	two channelized stream segments
	?	Stream	watershed	several possibly intermittent streams are within the water quality boundary	in Garapan
	AMME	Wetland	within park	yes	mangrove swamp/wetland
NPSA	Agaputuputu	Stream	Ofu	mouth	

Park	Name	Type	Location	Within park	Notes
(NPSA)	Tufu	Stream	Ofu	mouth	considered high quality
	Ulafala	Stream	Ofu	mouth	
	Vainuulua	Stream	Ofu	mouth	
	Alei	Stream	Olesega	yes	
	Vaaui	Stream	Olesega	yes	
	Sinapoto	Stream	Olesega	yes	
	Talaisina	Stream	Olesega	yes	
	Topea	Stream	Olesega	yes	
	Etemuli	Stream	Olesega	yes	
	Papausi	Stream	Olesega	yes	
	?	Stream	Tutuila	yes	upland stream on USGS topo map, possibly intermittent
	?	Stream	Tau	on border	
	Laufuti	Stream	Tau	yes	considered high quality
	Leua	Stream	Tutuila	yes	considered high quality
	Fagatuitui	Stream	Tutuila	yes	considered high quality
	Nu`utogo	Stream	Tutuila	yes	considered high quality
	Vaisa	Stream	Tutuila	yes	
	Gaoa	Stream	Tutuila	yes	
	Lausaa	Stream	Tutuila	yes	
	Faatafe	Stream	Tutuila	yes	
	Mulivai	Stream	Tutuila	yes	
	Vaiola	Stream	Tutuila	yes	
	Faigatoa	Stream	Tutuila	yes	
	Gagamoe	Stream	Tutuila	yes	
	Laolao	Stream	Tutuila	yes	
	Leafu	Stream	Tutuila	yes	
	Leasi	Stream	Tutuila	yes	
	Leele	Stream	Tutuila	yes	
	Matagimalie	Stream	Tutuila	yes	
	Pago	Stream	Tutuila	yes	
	Suaia	Stream	Tutuila	yes	
	Tofu	Stream	Tutuila	yes	
	Vaipito	Stream	Tutuila	yes	
	Vaisa	Stream	Tutuila	yes	considered high quality

Park	Name	Type	Location	Within park	Notes
(NPSA)	Vatia	Stream	Tutuila	yes	considered high quality, at Amalau
	Vatia	Wetland	Tutuila	yes	in Vatia village; both mangrove wetland and marsh
USAR	Halawa	Stream	watershed	no	East loch of Pearl Harbor
	Kalauao	Stream	watershed	no	East loch of Pearl Harbor
	Waimalu	Stream	watershed	no	East loch of Pearl Harbor
	Waiawa	Stream	watershed	no	Middle loch of Pearl Harbor
KALA	Waihanau	Stream	in park	all but headwaters	lower reaches intermittent; HI stream code: 4-1-01[25]
	Waialeia	Stream	in park	all but headwaters	HI stream code: 4-1-02
	Waikolu	Stream	in park	all but headwaters	diverted, HI stream code: 4-1-03
	Wainene	Stream	in park	headwaters	HI stream code: 4-1-04
	Anapuhi	Stream	in park	headwaters	HI stream code: 4-1-05
	Waioho`okalo	Stream	in park	headwaters	HI stream code: 4-1-06
	Keawanui	Stream	in park	headwaters	HI stream code: 4-1-07
	Kailiili	Stream	in park	headwaters	HI stream code: 4-1-08
	Pelekunu	Stream	in park	headwaters	HI stream code: 4-1-09
	Kauhako	Lake	in park		
	Iliopihi	Pond	in park	yes	man-made fishpond, anchialine, near windmill
HALE	Waiho`i	Bog	upper Hana	outside park boundary	
	State	Bog	upper Hana	outside park boundary	
	Big	Bog	upper Hana	yes	
	Mid-Camp	Bog	upper Hana	yes	
	Greensword	Bog	upper Hana	yes	
	New	Bog	upper Hana	yes	
	Flat Top	Bog	upper Hana	yes	
	Wai`ele`ele	Lake	upper Hana	yes	
	Wai`anapanapa	Lake	upper Hana	yes	
	"Wai Nene"	Lake	upper Hana	yes	not perennial, "Wai Nene" is informal name, below headwalls of Kipahulu Valley
	(unnamed)	Stream	Ka`apahu tract	yes	lower reaches intermittent

[25] The State of Hawaii defines a perennial stream as one which has permanent water along at least part of its course (HCPSU 1990). In contrast, the PACN defines a perennial stream as one which flows year-round to the sea. Thus, several streams classified as perennial by the State of Hawaii are considered intermittent by the PACN.

Park	Name	Type	Location	Within park	Notes
(HALE)	Pua`alu`u	Stream	Kipahulu tract	yes	HI stream code: 6-5-12
	Pipiwai	Stream	Kipahulu tract (`Oheo)	yes	Pipiwai/Palikea join in `Oheo Gulch (1.8 km to sea); HI stream code: 6-5-13
	Palikea	Stream	Kipahulu tract (`Oheo)	yes	Pipiwai/Palikea join in `Oheo Gulch (1.8 km to sea); HI stream code: 6-5-13
	Kalena	Stream	Kipahulu tract	upper portion	possibly intermittent, HI stream code: 6-5-14
	Koukouai	Stream	Kipahulu tract	upper portion	lower reaches intermittent, HI stream code: 6-5-15
	Kukuiula	Stream	Ka`apahu tract	upper portion	east boundary of Ka`apahu, lower reaches intermittent, HI stream code: 6-5-17
	Ka`apahu	Stream	Ka`apahu tract	yes	HI stream code: 6-5-18
	Leleka	Stream	Ka`apahu tract	yes	HI stream code: 6-5-19
	`Alelele	Stream	Ka`apahu tract	yes	HI stream code: 6-5-20
	Kalepa	Stream	Ka`apahu tract	yes	west boundary of Ka`apahu, HI stream code: 6-5-21
	(seasonal)	Stream	Kaupo Gap ?	?	mentioned in park communications
ALKA	?	?	?	?	unknown, pending designation of park boundaries
PUHE	Makeahua	Stream	mouth & part of body	mouth & part of body	upper part intermittent
	Makeahua	Wetland	"anchialine pool"	yes	anchialine, separated from stream by road
KAHO	Kaloko	Pond	in park	yes	manmade, with rock wall
	Kaloko	wetland	Assoc. with Kaloko Pond	mostly	anchialine
	`Aimakapa	Pond	in park	yes	manmade, with a sand berm, anchialine
	Anchialine	Pools	over 100	yes	also large complexes outside boundary
	`Aimakapa	Wetland	assoc. with `Aimakapa Pond	yes	anchialine
PUHO	"Royal"	Pond	in park	yes	brackish, manmade
	"Royal"	Wetland	in park	yes	anchialine, associated with unnamed pond complex
	Anchialine	Pools	several	yes	approx. 4 anchialine ponds & 3 anchialine waterholes
	Ki`ilae	Stream	Ki`ilae tract	yes	intermittent
HAVO	(intermittent)	Streams	Ka'u	yes	
	Anchialine	Pools	several complexes	yes	also some outside boundary (e.g., Great Crack)
	Ola`a	Bogs	Ola`a Tract	yes	perched bogs within Ola`a tract

ACKNOWLEDGEMENTS

The PACN would like to thank those who provided helpful comments and suggestions during the creation of this report, particularly the following individuals:

Anne Brasher	U.S. Geological Survey, WRD
David Foote	U.S. Geological Survey, PIERC
Terrell Erickson	USDA-NRCS
Robert Kinzie	University of Hawaii, Zoology Department
Robert Nishimoto	Dept. of Land & Natural Resources, DAR, Hawaii
Alison Sherwood	University of Hawaii, Botany Department
Gordon Smith	U. S. Fish & Wildlife Service
Reuben Wolff	U.S. Geological Survey, WRD